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ABSTRACT

Twin aims--to advance theory and to improve practice in science, mathematics, and computing education--guided the Educational Technology Center's (ETC) research from its inception in 1983. These aims led ETC to establish collaborative research groups in which people whose primary interest was classroom teaching and learning, and researchers concerned primarily with developing and testing theory, would keep each other honest. Several such groups identified targets of difficulty in the K-12 science, mathematics, and programming curricula and proceeded to develop experimental approaches including new technologies to improve teaching of these conceptually difficult topics. Most groups began with close observations of individual students and progressed to design materials and activities for teaching experiments which they conducted first with small groups and then with whole classrooms. Three of ETC's research groups had the following proposals: (1) using microcomputer based laboratory equipment and other technologies to teach students about heat and temperature; (2) infusing a programming "metacourse" into introductory classes in BASIC; and (3) teaching with the "Geometric Supposers" to incorporate inductive reasoning into traditional geometry courses. Included are goals, approaches, and implementation requirements of the innovations; discussion of the laboratory sites; and findings for introducing and integrating new technologies. (MVL)

TR88-3

COLLABORATIVE RESEARCH GOES TO SCHOOL: GUIDED INQUIRY WITH COMPUTERS IN CLASSROOMS

Technical Report

December 1988

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Collaborative Research Goes to School:
Guided Inquiry with Computers in Classroom

Technical Report

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TABLE OF CONTENTS

INTRODUCTION

GOALS

Twin aims--to advance theory and to improve practice in science, mathematics, and computing education--guided the Educational Technology Center's research from its inception in 1983. They led the Center (ETC) to establish collaborative research groups in which people whose primary interest was classroom teaching and learning and researchers concerned primarily with developing and testing theory would keep each other honest. Several such groups identified targets of difficulty in the K-12 science, mathematics, and programming curricula and proceeded to develop experimental approaches including new technologies to improve teaching of these conceptually difficult topics. Most groups began with close observations of individual students and progressed to design materials and activities for teaching experiments which they conducted first with small groups and then with whole classrooms.

By the spring of 1986, three of ETC's research groups had conducted their innovations with whole classes and were ready to learn what it took to carry them out in a range of regular school settings. These three innovations were: using Microcomputer-Based Laboratory equipment and other technologies to teach students about heat and temperature[1], infusing a programming "metacourse" into introductory classes in BASIC[2], and teaching with the *Geometric Supposers* to incorporate inductive reasoning into traditional geometry courses[3]. All three were all designed for secondary level courses, although other Center projects addressed elementary school subjects.

To illustrate and study the implementation of these ETC-developed examples of teaching with technology, the Center established laboratory sites in five Massachusetts secondary schools during the 1986-87 academic year. In these sites ETC supported and documented the process of implementing and extending research-based innovations under realistic classroom conditions. Lab sites were comparable to the gardener's cold frame--less protected than the hothouse environment of tightly controlled research classrooms but more fully supported than most school settings. Lab site teachers worked closely with the relevant ETC research groups to establish a dialogue between theorists and practitioners. In lab sites research-based innovations were translated into practice, while this experience became the basis for further educational research and development.

In summary, the laboratory sites project had two major goals:

1. To illustrate ETC's approach to teaching with technology as exemplified by three particular research-based innovations in several different kinds of school settings.

2. To learn what it takes to achieve this vision in regular secondary school classrooms.

BACKGROUND

The lab site project was designed to take into account lessons from previous efforts to reform teaching practice through the introduction of new materials and approaches developed outside the school system. Briefly summarized, these lessons included: focus on the teacher as the primary character in classroom innovation; generate support from the school administrators; support an on-site facilitator; present a clear vision of the desired teaching innovation; follow initial training with sustained assistance; build networks of innovators; sustain innovation through a community of reflective colleagues (Crandall, 1982; Little, 1982; Huberman, 1983; Lieberman & Miller, 1984; Sheingold, Martin, & Endreweit, 1985; and Cline et al., 1986).

As much as possible these principles guided the design and the process of establishing laboratory sites. ETC negotiated to establish laboratory sites at one high school in each of its four consortium member school districts and with an inner-city high school in Boston[4]. Initial conversations were held with central office administrators and then with the building principal in each case. These people identified appropriate personnel to introduce the laboratory concept first to department chairpeople and then to faculty. At each level of the school structure, people were invited but not required to participate.

Recognizing the value of collegial support for innovation (Little, 1982), an effort was made to recruit at least two teachers for each of the three innovations at every laboratory site. This ideal was compromised, however, when only one teacher taught appropriate courses or chose to volunteer for the project.

Administrators at each site identified an on-site liaison to help coordinate the range of lab site activities and to serve as an observer of the project from the school's perspective. While the liaisons varied in position and kinds of experience, they were all veteran staff members. Their length and breadth of familiarity with each school proved invaluable in negotiating the complex relations between ETC and the schools.

ETC employed three advisors, one for each subject matter strand of the project. The advisors were experienced teachers, accustomed to teaching with technology, who became members of the relevant ETC resesarch group. They met regularly with the teachers in lab sites, helping to plan lessons, adapting materials, observing classes, and consulting about teaching strategies. Their role was to help translate research results into terms that were feasible for the teachers and to help

analyze implementation issues. They complemented the liaisons' site-based perspective by observing and analyzing a particular subject matter strand of lab site project across sites. Lab site project personnel are shown in Table 1.

Table I

Laboratory Site Project Organization

Overall Project Direction and Coordination

ETC Project Leader
ETC Research Assistants
Liaisons from five schools
Common Ground teleconference system
Assistance from the Education Collaborative of Greater Boston

Science Strand

ETC Heat and Temperature Research Group
ETC Advisor
Teachers from four school sites

Programming Strand

ETC Programming Research Group
ETC Advisor
Teachers from five school sites

Geometry Strand

ETC Geometry Research Group
ETC Advisor
Teachers from four school sites

By May, 1986 formal agreements were set between ETC and each of the five schools. Thanks to a generous gift from Apple Computer, Inc. of computer hardware with related peripheral equipment and software, ETC provided all necessary hardware and equipment, unless the school system already owned sufficient computers. ETC provided teachers and liaisons initial training, followed by regular consultation and support throughout the academic year. The Center also paid teachers and liaisons a stipend. In exchange, the school system would provide facilities and supplies for a computer laboratory, maintenance and security for hardware loaned by ETC, and a dedicated telephone line for the lab site electronic conference. Finally the schools agreed to release

lab site participants from school responsibilities for two days during the academic year to attend lab site activities.

At the end of June, 1986, ETC held a conference for all lab site project participants including teachers, liaisons, key administrators from the lab site schools, and researchers from ETC. The primary purpose of this two-day event was to introduce school people to the innovations they would be introducing to their classes, and to begin to develop connections between the school-based and university-based participants in each strand of the project. The conference also introduced project members to an ETC-designed teleconferencing system, *Common Ground*, that would be used to link lab site participants throughout the project. Lab site teachers were given copies of the materials they would use with their students in the coming fall. Geometry teachers were also offered the opportunity to take home a computer during the summer so that they could become familiar with the *Geometric Supposer* software.

During the 1986-87 academic year lab site teachers met regularly with the members of the relevant ETC research group. The liaisons met simlarly with the project director and advisors. These meetings were an occasion for dialogue about the process and effects of carrying out the teaching innovation. During these meetings school people became clearer about the rationale behind the teaching materials and activities; by the same token the researchers learned about the clarity, feasibility, and effects of their materials. The aim of these meetings was to promote what Wagner (1988) calls "interpretive consultation" whereby school practitioners learn about research results while researchers become more aware of the problems of practice.

An electronic conferencing system was established, to supplement face-to-face contacts between lab site participants. Members of the ETC Computer Conferencing research group provided training and support in the use of this system and studied the nature of its use by lab site participants. Their research is summarized by West and McSwiney (1989).

Methods

The laboratory site was designed to learn what it takes to carry out ETC-developed innovations in regular schools. Each of these innovations exemplified an approach to teaching that we call technology-enhanced guided inquiry. In this approach, the computer is used not as a replacement for the teacher, but as a tool to enable teachers and students investigate problems by gathering and analyzing data and developing and testing explanations or solutions. The teacher's role in this approach is to present problems, to guide students as they explore these problems either alone or in small groups, and then to help students synthesize their findings in terms of the teacher's agenda for

the class. While the primary focus of the project was the implementation of ETC's innovations, it was hoped that the research would shed light on more general questions about the requirements for integrating computer technology and active inquiry into the core curriculum and practice of schools.

The research was based on an interactive conception of the process of change in school practice. Some students of school change have focused on the implementation of specified innovations (Havelock, 1969); others have focused on features of the implementation context including the influence of key actors (Weatherly & Lipsky, 1977) and of organizational values and structures (Farrar, DeSanctis, & Cohen, 1982; Cohen, 1987). Acknowledging the interactive influence of all these elements in the change process, we studied the innovations themselves, the teachers, and the school contexts within which lab sites operated. A central concept in tracing the implementation process was the notion of mutual adaptation (Berman and McLaughlin, 1974; McLaughlin, 1987; Elmore & McLaughlin, 1988) whereby innovations, individual practice, and institutional contexts change during the process of implementation in order to accommodate each other. Our purpose was to understand the kinds of obstacles that arose during this process, the kinds of accommodations that were needed, and the sorts of resources and assistance that supported these kinds of accommodation.

The research in laboratory sites included two studies. The study reported here focused at the school level. Its aim was to trace the implementation of the three strands of the project, clarifying what promoted and impeded this process with particular focus on the "goodness of fit" between the innovations and the settings where they were carried out. The second study, focused on teachers involved in the geometry strand of the project, is reported by Lampert (1988a). It analyzed the way teachers' accommodated their thinking and their practice through experience with the geometry strand in laboratory sites.

Multiple sources of data were monitored throughout the 1985-87 year of the project. Lab site project researchers attended all meetings of the research groups with the lab site teachers. They also visited lab sites regularly throughout the year, observing selected lessons and interviewing teachers, liaisons, and other key actors. Advisors met regularly with the lab site project leader and to discuss the many aspects of mutual adjustment necessary to increase the goodness of fit between innovations and lab sites. Field notes were made of these observations and interviews and some key meetings were tape recorded and transcribed. These data were coded and analyzed for two purposes: (1) to characterize the three innovations and their implementation requirements, and (2) to trace the implementation process at each site. An interim report was prepared mid-year and circulated to all lab site participants. Participants were asked to review the interim report for

accuracy of description and interpretation; their comments were taken into account in preparing this final project report.

The next section analyzes the three innovations and their implementation requirements. Then case studies of two laboratory sites are presented. A third case study has been prepared by McDowell, et al. (1987). The final section analyzes the implementation of technology-enhanced guided inquiry, drawing on data from all five laboratory sites. It discusses the prerequisite conditions for introducing computer technology into schools as well as the more complicated conditions necessary to integrate technology-based innovations into the core school program. It concludes with recommendations for research and practice.

THE INNOVATIONS

SCIENCE INNOVATION

Goals and Approach

Teachers participating in the science strand of the lab site project were expected to teach lessons developed by the ETC Heat and Temperature Research Group which aim to help students distinguish between these two closely related concepts. Their lessons approached this distinction, a fundamental prerequisite for understanding energy transfer, through analysis of phenomena which prompted advancements in the history of thermal physics. Computer software and hardware developed at Technical Education Research Centers (TERC) known as Microcomputer-Based Laboratory (MBL)[1] equipment were employed to help to make these phenomena more noticeable.

The Microcomputer-Based Laboratory (MBL) equipment included two thermal probes and a heating coil connected through an interface box to the game port of an Apple microcomputer. Equipped with special software the computer measured and displayed data about thermal phenomena. MBL technology was designed to give students "direct perceptual access" (quoting its designer Robert Tinker) to phenomena that are inaccessible in everyday life. For example, though most students are familiar with thermometers which measure temperature, most have no experience with instruments that indicate changes in heat. MBL equipment allows students to deliver a calibrated amount of heat to a substance and displays the resulting change in temperature as a function of real time on a graph that also indicates the points when heat was added. With a few keystrokes this information can be displayed in a table of data. Display of real-time changes in data, coupled with easy methods of analyzing data were thought to permit students to focus more on

understanding the meaning of the data rather becoming preoccupied with lengthy calculation. Lab site teachers used this apparatus as well as software that simulated experiments conducted with similar equipment.

Although the MBL equipment can enable open-ended exploration, the lessons used by lab site teachers directed students to gather and analyze specific data as they performed particular experiments. Lab site teachers received materials for approximately one dozen lessons in which students conduct experiments that illustrate such thermal phenomena as latent heat, specific heat, and the influence of mass on the relationship between heat and temperature. Teachers selected lessons from this set, depending on their particular course content and their students' ability level. In most cases they taught a unit that covered 2-3 weeks of their course.

The overall approach employed by lab site science teachers did not differ radically from most laboratory-based science lessons. Students were introduced to the purpose and procedures of an experiment and then carried out the investigation. They were expected to record their procedures and findings and then analyze their results with an eye to developing a theory to explain their data. While the overall structure of these laboratory sessions was not unusual, the pedagogical theory underlying the technology and the ETC-developed lessons was.

The lessons developed by the ETC Heat and Temperature Research Group were based on a conjecture that many of the same beliefs and misconceptions once held by scientists are still harbored by today's students. These ideas are not easily changed because they are reinforced in the children's minds by everyday experience and a complex network of interconnected ideas. Teaching students the physicists' notions about heat is not a simple matter of instruction; it requires stimulating and supporting students to make a fundamental conceptual reorganization. The same phenomena and experiments that served to advance scientists' understanding of thermal physics might prompt students to question their own beliefs and struggle to revise their notions.

Overall, the ETC lessons reflected a pedagogical approach that depended upon careful efforts to present students with experiences they could not explain with their current conceptions and then to guide them to rethink their ideas. The computer alone was not expected to stimulate student learning. Rather, the approach was assumed to require a skilled teacher who could help students focus their attention and guide their reflections to formulate more sophisticated understandings of the phenomena they studied.

Implementation Requirements

Hardware and Software

The science strand was the most complicated of all the lab site innovations with respect to hardware and related equipment. The Microcomputer Based Laboratory required not only a computer and software, but also peripheral attachments described above. The software disk included five different programs that allowed the user to calibrate the themal probes and then carry out the activities described earlier.

Neither the hardware nor the software was commercially available at the time the lab site project began. The only place they could be acquired was TERC, an educational research and development organization where the MBL equipment had been invented and originally studied. TERC agreed to supply ETC with 30 heat/temperature MBL kits for the lab site project, but the promise proved difficult to keep. As a development center TERC was accustomed to producing prototype equipment for research, not large numbers of kits for use in several schools. At the time the lab site project began, neither the design nor the method of assembling the equipment was fully specified. Consequently, production was delayed and the equipment proved to be fragile and unreliable. The first lab teachers who tried to teach with this equipment found that approximately 2/3 of the probes malfunctioned during the first or second class period they were used. More dependable probes were provided later in the project, but equipment failures continued to be a significant difficulty.

Materials and Other Equipment

Teaching heat and temperature lessons with MBL required a considerable amount of equipment in addition to the hardware. For most lessons, each lab station needed 2-3 beakers, a graduated cylinder, a thermometer, and a stirring rod. Some lessons also required water, ice, and a hot plate or other means of heating water. While these items might be thought of as usual laboratory equipment, not all lab [illegible]es had all the equipment. Even if they did, it had to be transported from the science laboratory to the computer laboratory where MBL lessons were conducted.

Besides this equipment, the lessons depended on the usual teaching materials such as lesson plans for teachers and students, work sheets, and problem sets. The materials given to teachers at the beginning of the project were rather sketchy lessons used by members of the ETC Heat and Temperature Group in their classroom-based research. They outlined five laboratory lessons and

some homework assignments. They did not include a teacher's guide, syllabus, manual for the hardware and software, or teaching aids. As the project proceeded, it became apparent that, unlike both the geometry and the programming strands, the science strand had little curricular material beyond the lessons taught by researchers.

Because the set up of computer, related hardware, and other equipment was complex, students and teachers needed directions for setting up the apparatus. Their lack at the beginning of the project emphasized the need for instructions, diagrams, or other means of clarifying how the equipment should be assembled.

The facilities needed for the MBL lessons were similar to, but somewhat more elaborate than, the arrangements needed for the other two lab site innovations. Like the others, an MBL session required a computer laboratory. Participants in the lab site science strand had various opinions about the number of students who could most effectively work at one station, but the general view was that 2-3 students was usually best. Because MBL experiments involved additional equipment besides the computer, students needed room next to the computer where beakers of water, probes, and so on could be safely used and observed. They also needed room for their instruction sheets and other papers for recording their observations. The computer lab had to be wired with outlets or power strips to provide three outlets per station. It also needed a sink; otherwise water must be carted in and out.

Finally, the labs need storage space so that the peripheral equipment could be put away between science classes. In some ETC lab sites there were storage cabinets; in others the MBL equipment was stored on a rolling cart that the science teacher moved as needed from classroom to computer lab. The importance of adequate storage space became apparent in the early attempts to carry out this innovation when the lack of same significantly disrupted both the heat/temperature lessons and the use of the computer lab by other classes.

Knowledge, Skills, and Beliefs

<u>Knowledge</u>

Clearly, the teachers involved in the science project needed to understand the thermal concepts and phenomena they were teaching about. Because their lessons were narrowly focused around particular topics, they did not face quite the same uncertainty as *Geometric Supposer* teachers about the realms of knowledge their students might explore during a session.

Nevertheless, to teach this material effectively teachers needed comprehensive understanding of their subject matter and of their students' common misunderstandings.

Like programming teachers, most science teachers were accustomed to teaching lab classes with students divided into small groups working simultaneously at different paces on a problem or experiment. Knowing how to monitor the activities of these various groups and to support their learning effectively during the lab session was a key part of carrying out the MBL-based lessons successfully. A presumed advantage of MBL is that it presents and relates information in meaningful ways allowing students to interpret data during their lab session, rather than having to wait until they have performed lengthy calculations and translations with data. To capitalize on this potential advantage teachers must be able to help students recognize and use key opportunities to challenge their existing ideas and to rethink their understandings during the lab.

The technology in this strand presented a significant knowledge hurdle for most of the teachers. The technology was complex, fragile, and must be used in a precise way. Most lab site science teachers had not used computers before, let along taught with them. Knowing how to set up the computer-related apparatus, what each component did, and how to convey this information to students was no easy matter for most of the teachers.

Skills

The MBL heat and temperature lessons were perhaps the most demanding of teaching skill, especially for teachers new to computers. The lessons themselves were complex in at least three ways which gave rise to a fourth sort of complexity. First, they were conceptually difficult, involving concepts that were hard for students to grasp and keep in mind. [CITE ETC Heat and Temperature Research Group reports for a fuller report on the reasons that this topic is a target of difficulty.] Second, the lessons were technologically complex, involving a lot of unfamiliar, fragile equipment which was unable to function unless used in a precisely correct fashion. Third, bringing students together with the necessary equipment and separating them safely and tidily at the end of the period was a managerial challenge. Finally, teaching students to keep track of all three kinds of complexity at once required special organizational skill in itself.

Beliefs

The MBL lessons reflected an assumption, obviously, that students were capable of learning to keep track of all these kinds of complexities simultaneously. The developers did not assume, however, that students easily accomplish the conceptual reorganizations that deep understanding of

difficult scientific ideas requires. They perceived much of traditional science instruction to be too superficial, more focused on teaching students to memorize vocabulary and formulae than on providing students with the kinds of experiences likely to change their minds in any fundamental way. Members of the ETC Heat and Temperature Research Group assumed that teachers would need to combine the experimental lessons with sensitive analytic discussion to help students comprehend their findings. These assumptions remained tacit, however. The Research Group did not provide materials or explicit guidance for teachers regarding the methods or content for such discussions with students.

PROGRAMMING INNOVATION

Goals and Approach

The goal of the Programming Metacourse[2] was to help students learn better to understand and to write computer programs through a series of lessons designed to be integrated into introductory courses in BASIC. It was called a metacourse because it focused on key mental models, fundamental concepts, and heuristic strategies that form the conceptual core of any programming course.

The Metacourse reflected a theory of learning that students benefit from being explicitly taught ideas and strategies that often remain tacit in high school programming courses. For example, Metacourse lessons clarified the purpose and action of programming statements, as well as their more commonly emphasized syntax. Students were also taught mental models, strategies, and attitudes that facilitate effective planning and production of programs. Teachers presented this information, using diagrams on overhead projectors as well as handouts prepared by the ETC research group. Students were then given opportunities to apply this information and to practice the strategies through problems that they worked on during class sessions in the computer lab or through homework. Within the overall guided exploration approach of ETC-developed innovations, the Metacourse lessons themselves tended to provide more guidance than opportunities for student exploration, which were assumed to occur in other lessons and in homework assignments.

The Metacourse consisted of eight or nine lessons designed to be interspersed throughout a one semester introductory BASIC course. The developers saw them neither as a complete course, nor as a modular curriculum unit, but rather as a "vitamin shot" to be integrated into any standard course in BASIC. Indeed, with minor revisions the lessons could be used in introductory courses teaching other programming languages. ETC researchers expected that teachers would not only

teach each of the Metacourse lessons, but also "infuse" the concepts and strategies from the Metacourse into other lessons in their course. Thus the pedagogical approach involved regular reiteration of key concepts by teachers accompanied by frequent practice of strategies and repeated application of concepts by students. Lab site teachers usually found they needed more than nine class periods to complete the Metacourse lessons and they did infuse Metacourse activities into the remainder of the course. Overall, the Metacourse probably influenced, either directly or indirectly, 20-30% of the semester's lessons in lab site teachers' programming courses.

Implementation Requirements

Hardware and Software

While the programming component required computer hardware and BASIC software, the ETC innovation did not require any equipment different from what is used in conventional programming courses. Thus the hardware and software requirements constituted no difficulty at all in lab sites.

Materials and Other Equipment

The Metacourse materials provided to lab site teachers were extensive and precise. For each of the lessons, teachers were given not only a detailed lesson plan but also recommended scripts as well as a sequence of overhead transparencies designed to help them present particular concepts and activities. The Metacourse materials also included handouts for students: instructional diagrams, problem sets, and homework assignments. A Minimanual provided with the Metacourse materials was designed as an easily accessible source of information about BASIC commands to help students over the initial hurdle of information overload that many experience as they begin to learn a programming language.

The ETC designers of this innovation took pains to invent and produce all the materials they could anticipate teachers' needing. Lab site teachers were given sufficient copies of all materials to provide for all the members of participating classes. They were even given enough Minimanuals to supply each station in the computer lab as well as each student, in case some students forgot to bring their Minimanuals to class.

Knowledge, Skills, and Beliefs

Knowledge

The knowledge of programming in BASIC that teachers needed in order to teach the Metacourse was very elementary, basic so to speak. The programming content covered in the Metacourse was standard in most beginning BASIC courses. Thus the content knowledge required for this innovation, while important, could be readily assumed for instructors in programming.

Knowledge of the underlying theory of learning implicit in the Metacourse and the rationale behind its design was more problematic. These ideas were seldom discussed explicitly with lab site teachers so it was difficult to know whether teachers understood these ideas, accepted them, or knew how to apply them to their teaching. In discussing an earlier draft of this paper with Programming Group members, several stated that teachers probably were not fully aware of the conceptual framework that gave rise the the Metacourse. They thought this lack might hamper the teachers' ability to infuse Metacourse elements in ways that required inventing new applications of these elements. The extent to which teachers understood and needed to understand the theory of learning implicit in the Metacourse is a topic for further investigation.

Skills

The Metacourse was designed to be integrated into a course that follows some form of guided exploration format overall. In this format teachers provide some direct instruction on the material to be covered, then assign problems that students explore, and then help students synthesize their findings with the teacher's intellectual agenda through conversations with the whole class, comments on students' papers, and other means. The Metacourse lessons themselves are generally designed to cover the first two sorts of activities, classroom instruction by the teacher and problems to be assigned to students for in-class or at-home work. Most programming instructors follow some version of this approach in their courses so the Metacourse approach did not require them to develop new teaching or classroom management skills.

What was demanding in the Metacourse was the need to follow a detailed, scripted, lesson plan designed by someone else. Lab site teachers were encouraged to modify the lessons enough to allow them to accommodate their particular styles, students, and curricula, but some teachers found the seam between their own approach and that of the Metacourse to be a ragged one. Their experience highlighted the skills needed to teach such a highly-specified innovation, especially when teaching it for the first time under conditions constrained by research requirements. Several

teachers felt they would modify, rearrange, or omit segments of the Metacourse and pace the lessons differently if they used it with more freedom than the ETC Programming Research Group could permit during its lab site research.

Beliefs

While most of the pedagogical approach encompassed by the Metacourse was clear and acceptable to the laboratory site teachers, in a few respects there was not such a clear meeting of the minds. At least some members of the ETC Programming Research Group that designed the Metacourse assumed that students are both capable of and benefitted by conscious awareness of their own thinking processes and of the teacher's intellectual agenda. Not all lab site teachers shared these assumptions. Some believed that high school students may be more confused than benefitted by thinking about their own problem solving approaches.

The Metacourse Minimanual reflects an assumption that students benefit from ready access to reminders about the purpose, action, and rules of syntax of key programming commands. At least one lab site teacher felt this "crib sheet" might discourage students from taking careful notes and introduce them prematurely to concepts they were not yet ready to use.

> I don't let my students use the Minimanual. It just encourages them to try using procedures they don't really understand. Maybe they heard about them once in another course, see them in the Minimanual, and then try to use them in their programs. When they don't work the students ask me to help and I say, "Just wait until I've taught you that procedure and then you'll know how to use it." Otherwise they just wind up confusing themselves.(J.H.)

Although other lab site teachers did not appear to share these concerns about the Minimanual, this teacher's remarks reflect a set of assumptions common to many school people. They are reminiscent, for example, of some lab site geometry teachers' worries that students would not learn geometry properly if they discovered it on their own. A deeply held belief that students ought to learn a subject in the sequence and context that their teachers have deemed most advantageous can make the guided exploration approach seem inappropriate and perhaps irresponsible.

The Metacourse lessons reflected an assumption that students were capable of reading and writing at approximately the eighth grade level and that they had the motivation and confidence to read directions carefully. Indeed, this expectation was probably reflected in all the lab site innovations. Not all high school students have these skills and attitudes, however. Several lab site teachers felt that some Metacourse materials and lessons (particularly the lesson which taught

stategies for planning complex programs) required reading and writing skills that exceeded their students' capacities.

Overall, the "goodness of fit" between the assumptions held by lab site teachers and those underlying the Metacourse design might be characterized as moderately good with a couple of incongruent areas.

Clearly, a teacher might possess all the knowledge, skills, and beliefs described above, but not be inclined to act on them in class. In the lab sites programming teachers' inclinations seemed significantly affected by their assessments of their students' academic abilities. The teachers who expressed the most reservations about fully adopting the Metacourse approach were those who said that their students needed a different type or pace of instruction. They thought the course was too "high level" requiring complex thinking, a faster pace, and less attention to practice than they believed their students needed.

GEOMETRY INNOVATION

Goals and Approach

The geometry innovation employed microcomputers equipped with a set of software called the *Geometric Supposers*[3], which is supplied on three floppy discs. The *Geometric Supposer* s software allows the user to make geometric constructions of the sort created with a compass and straightedge. It also provides a facility to measure angles, areas, and line segments and to perform arithmetic operations on these numerical data. The software remembers a construction as a procedure and allows the user to repeat the construction on another geometric figure of the same sort, either a random figure or one specified by the user. Thus the software enables students and teachers to gather geometric data, observe patterns in visual and numerical data, and test conjectures about geometry.

In the approach developed by the ETC Geometry Group, the *Supposer* was used to integrate inductive reasoning into a full-year geometry course. Lab site teachers received problem sets that addressed a range of topics typically included in the traditional geometry curriculum. Teachers would introduce a problem and related concepts to the entire class. Then students worked on these problems, usually in pairs, using the *Supposer* at computers grouped in a laboratory setting. As they worked at the computer their explorations were guided by the problem itself as presented on the exercise sheet, by the structure of the software (e.g. its facilities and menu), and by the teacher. After students worked on computer-based assignments teachers led post-lab class discussions to help students synthesize their findings in relation to the teachers' agenda which included the

standard geometry curriculum of definitions, axioms, theorems, and proofs. Some teachers also used the software with a large monitor in whole-class lessons like a dynamic chalkboard to illustrate demonstrations or class discussions. Most laboratory site teachers taught and discussed *Supposer*-based lessons episodically throughout their year-long course so that the innovation influenced 25-75 percent of the class periods.

Implementation Requirements

Hardware and Software

The ideal arrangement for teaching with the *Supposer* is a classroom supplied with computers as well as the standard equipment such as chalkboards and desks. A sufficient number of computers would allow the entire class to work at once with no more than two students per computer. In addition, one computer equipped with a large monitor is useful for demonstrations. In such circumstances the class can move easily between computers and desks. One lab site accomplished this arrangement, while the other three where the geometry strand was taught coped with a more common, less convenient situation. In the latter three, the computers were housed in a laboratory some distance from the classroom. The computer lab was used by other classes, as well, requiring teachers to schedule computer-based lessons well in advance. The logistics of deciding, publicizing, and convening class in one of two locations were burdensome. Furthermore, especially in the first year, teachers found it difficult to predict exactly when they would be ready to begin or end a computer-based sequence of lessons. This unpredictability further complicated scheduling access to hardware.

The *Geometric Supposer* software is contained on floppy disks suitable for use in an Apple // computer. (A version for IBM computers is not available.) The software publisher, Sunburst, provided lab site teachers with lab packs containing 10 copies of the disk. It is possible to use the software after the disk has been booted and removed, but lab site teachers found the lab packs much more convenient.

Materials and Other Equipment

Besides the hardware and software teachers needed courseware such as lesson plans, problems and other activities, and work sheets to structure actual lessons. The ETC staff working on this project provided one set of problems in the summer of, 1986, followed by another set of problems in the fall, suitable for teaching about triangles with the *Supposer*. As the year progressed, the ETC staff provided additional problems dealing with topics usually covered in the traditional

geometry course. These materials did not provide suggestions about teaching, but did give teachers a set of problems and solutions to use with their students.

ETC staff encouraged teachers to regard the problems they distributed as illustrative examples to be selected, modified, and supplemented as necessary to meet each teacher's curriculum and students' needs. Although the designers believed the problem sets might be used with students without modification, most teachers found that they needed to create similar but different problems designed particularly for their classes. Suitable courseware, including appropriate problems and well-designed exercise sheets, became recognized as an important prerequisite for effective teaching with the *Supposer*. [See Yerushalmy, Chazan, and Gordon (1988) for a fuller discussion of characteristics of good problems.] Teachers found, for example, that work sheet design was a tricky business. The sheets must present problems clearly, provided sufficient guidance to help students proceed effectively, yet not be so structured as to deny students the opportunity to make the kinds of analytic leaps which are central to the process of making mathematics. As the year progressed, teachers shared their exercise sheets with one another, and the file of usable classroom materials grew.

Knowledge, Skills, and Beliefs

Knowledge

In most geometry classes teachers control what gets taught by deciding what to cover in their presentations and what to assign in their texts. They generally assign problems that involve deductive reenactments of previously discovered mathematics rather than problems that encourage students to create mathematics through open-ended exploration. Under these circumstances, teachers can anticipate what will be discussed during a given lesson and can refresh their minds on that subject matter in preparation. With the ETC approach teachers relinquished some of their control over the content and sequence of material to be addressed. Students given the opportunity to explore problems might find relationships, invent ideas,or raise questions that fell outside of the teacher's intellectual agenda for that day. Indeed they might fall outside the teacher's agenda for the entire course or the teacher's own domain of knowledge. In order to deal deftly with potentially unanticipated ideas, teachers need a detailed map of the geometry territory students would explore. Besides a thorough knowledge of geometry, teachers also needed to understand the process of reasoning inductively and deductively and of integrating knowledge from both sorts of thinking to develop mathematics. Teachers needed to understand how to model, present, and encourage such thinking so that students could understand it without oversimplifying the process into a counterproductive series of rote steps.

As teachers worked with the *Supposer* their own knowledge of geometry grew, along with their ability to anticipate the kinds of confusions and discoveries students might encounter with particular problems. With this growing knowledge teachers became better able to plan a structure for eliciting, analyzing, and discussing the conjectures and questions that students presented. Initially, however, teachers felt significantly challenged to rethink their course goals, reconsidering old material and adding new material.

Using the *Geometric Supposer* in this approach also required familiarity and fluency with the software. ETC gave lab site geometry teachers computers and copies of the software and its manual (thanks to generous donations from Apple Computer, Inc. and Sunburst Software, Inc., respectively) during the summer, after the two-day introductory conference, and well before they had to begin using it with their students. Some teachers began exploring the *Geometric Supposer* during the summer; others waited until September to begin. All found that they needed time to work with the software in private before they were comfortable using it with students or supervising students as they worked with the *Geometric Supposer* during lab periods.

Becoming sufficiently familiar with this technology consituted a significant hurdle for the teachers, most of whom had not used computers in their classrooms. Many teachers were surprised by their students' ease in entering the software environment and by their own slower, but fairly smooth entry. Nevertheless, the process of becoming fully knowledgeable about the software's facilities, and fluid with the menu required a significant amount of effort by teachers. This was necessary before teachers felt confident enough to work with the technology in front of the class or to take full advantage of this tool to enrich their geometry teaching.

<u>Skills</u>

For most lab site geometry teachers, this approach required a significant, perhaps even radical change in the structure and process of their accustomed practice. Most teachers taught their traditional geometry course through lectures and demonstrations during class. Teaching geometry inductively through guided exploration required teachers to take on a different role in the classroom, to organize people, time, space, and activities differently, and to help students learn to play an unaccustomed part in the classroom.

Teachers needed to shift more attention to the process of cultivating within their students the confidence and ability to generate ideas. The geometry advisor refered to this process as "creating an intellectual community where teachers and students share responsibility for teaching and

learning." For a teacher the process includes taking everyone's ideas seriously, explicitly stating and reminding students of their responsibilities, supporting and encouraging students through the doubts (sometimes expressed as anger) that they often experience as they take on this unfamiliar role. Nurturing this culture is an important part of all steps in the guided exploration process: presenting a problem, providing guidance as students work through a problem during a lab session, and helping students synthesize their findings with the teacher's intellectual agenda.

Besides skills for presenting and soliciting knowledge, teachers needed particular management skills ranging from the mundane--a way to tell students whether class would meet in the lab or in their regular classroom--to the more fundamental--assessing students' work.
Running a lab session in which students work individually or in pairs at 10-15 different stations is different from delivering a lecture while the whole class listens quietly. Lesson plans for lab site sessions had to take into account that students might work at different paces, for example. Most teachers found it advantageous to assign several problems so that students who finished one quickly could move on to another. Capturing the attention of students' engrossed in their work during a lab session, figuring out a way to monitor whether students were spending their time productively, encouraging useful consultation among students at different work stations--all of these challenges must be faced as teachers learned to supervise effective lab sessions.

Likewise, orchestrating a productive discussion after a lab session took special skills. Teachers sought ways to help students share their findings with each other and with them so that everyone could think about them before a post-lab discussion. One lab site teacher found it useful to assign readings so that students would come to class with some of the concepts that she hoped to emphasize in the course of the discussion. The challenge of connecting students' ideas with the teacher's agenda was particularly acute during post-lab discussion periods. [See Lampert, 1988b for a fuller discussion of teachers methods for coping with this challenge.]

Grading student papers that report results on open-ended problems is much more difficult than correcting multiple-choice exams or problems with right answers. Teachers needed ways to hold students accountable for progressively more complete and sophisticated performances in analyzing problems inductively. They also needed ways of responding thoughtfully to the mountains of paper students generated in response to open-ended assignments.

Overall the geometry innovation required multiple, significant changes in most teachers' accustomed practice. They had to develop new skills for dealing with subject matter, with the mechanics of their course including technology, schedules, and facilities, with the intellectual and social intercourse among members of the class, and with assessment strategies that remained

accountable to the traditional evaluation measures while acknowledging the new goals encompassed by the innovation.

Beliefs

In many ways, the geometry innovation generated more conflicts with teacher's customary assumptions than the other lab site innovations. In part this was a result of its scope--it was intended to alter a significant proportion of the lessons taught throughout an entire year-long course, whereas the other innovations affected a smaller segment of a course. Teachers might find it reasonable that students could discover or invent a few ideas while most of the course would consist of didactic presentation. But the *Geometric Supposer* innovation assumed that students could effectively discover or invent a great deal of the geometry taught during a first year course.

Other assumptions implied by the *Geometric Supposer* project, which were uncomfortable if not entirely alien for most of the lab site teachers included:

- Students can learn things well that the teacher never taught.
- Students can learn things even if they weren't presented in the sequence that the text book or the teacher's customary course presents them.
- Teachers don't always have to know the answer or to be right.
- Geometry can be a fascinating subject even when it is not deductively constructed in a elegant fashion from a parsimonious set of axioms.

In short, the Supposer-based guided exploration approach to geometry challenged many of the teachers' assumptions about the course content and its sequence, about the appropriate ways of teaching and learning this material, and about the roles that students and teachers play in classrooms. These points are explored further by Lampert (1988a).

TWO LABORATORY SITES

NORVILLE

The School

Norville is a sprawling near-suburb of Boston with 83,622 residents. Their per capita income was $11,609 in 1980, and there was essentially no unemployment. Nearly half of its inhabitants o· ɜr 25 year of age have completed 4 years of college, 96% are white, and only 11.5% were born outside the U.S. Norville has customarily supported its schools with enthusiasm. A few years ago when the city discovered a surplus in the treasury, the school superintendent argued successfully that buying computers for the schools was a wise "capital improvement." While faculty numbers have been cut recently in response to declining enrollments, the school department has also responded to this situation by reducing teaching loads and scheduling time for teachers to use on planning and professional development. These blocks of time, a most precious resource in schools, are a powerful sign of deep commitment to quality education.

Norville Central High School is one of two comprehensive high schools serving this community. The three-story brick school and its surrounding playing fields and parking lots cover a multi-acre site in an upper middle class neighborhood of large homes and well-kept yards. Students tend to stay at Norville Central. Ninety-one per cent of the 1983 graduating class had spent their entire career at Norville Central; during the 1983-84 school year only 27 students withdrew from the school for reasons other than moving out of the district, and some of those were students transfering to private schools. The student body at Norville Central is also ethnically homogeneous. Only 7% of Norville Central students belong to minority groups and most of this group (4% of the total) are bussed from Boston as part of an urban/suburban student exchange program.

Entering the school, one climbs a ight of stairs to enter Main Street, a wide skylit corridor which seems to continue for miles. Between class periods Main Street swarms with multitudes of the school's 2200 students and 205 faculty members. Students visit their friends and their lockers, which flank one side of Main Street, as they move between classes. Even during class periods students may be found on Main Street, clustered in small groups or occasionally consulting with one of the adults assigned to monitor Main Street. Their presence during class reflects the school's open campus policy, which allows students considerable freedom to go where they wish at times they are not assigned to a class. This frequently modified policy is a common topic of the continual heated debates that occupy faculty committees and task forces in this fiercely democratic school.

Veering off Main Street are a series of large corridors, each painted a bright primary color that matches the banks of lockers next to it. Large signs stenciled on the walls mark each of these color-coded areas as one of four Houses. The house divisions cut through the physical structure, top to bottom. Each house has its own headmaster office, common room, and guidance counsellor just off Main Street. Students and faculty are randomly assigned membership in a house, a membership which appears to carry real emotional weight and a sense of strong identification for teachers. A program instigated in one house during 1986-87 encouraged students who were having difficulties to take the bulk of their courses from the faculty in their own house, a process intended to promote a sense of belonging to a community for the students. The program was so successful that two other houses were considering adopting the same plan for the coming year, despite the scheduling nightmares it created.

While the social organization (including student guidance and discipline) of the school is orga ed primarily around the house structure, curriculum at Norville Central is managed by subject-based departments. The departments are organized by floors which literally, as well as figuratively, cross-cut the vertically organized house structures. It is a cumbersome system: policies and procedures vary from one house and department to another and the lines of control and power have deliberately been snarled. Faculty at Norville Central say they have two sources to go to with problems and suggestions, a duplication which most teachers believe increases their individual freedom.

Besides the colorful corridors leading to classrooms, the visitor to Main Street sees myriad reminders of the many programs and activities at the school. Student-made posters announce plays, dances, yearbook sales, and fund-raising campaigns. Glass cases contain artful displays of students' photographs, sculpture, and paintings. Big signs point the way to the auditorium and the library. Finally, after traveling several hundred yards, the visitor reaches a sign pointing up the stairs to the principal's office, at the rear of the third floor. After an initial trip to the office, the repeat visitor learns to dispense with this detour and proceed directly to the meeting place agreed upon for his appointment. Registering first at the office, a ritual required in most schools, is not closely observed at Norville Central.

Old-timers at Norville Central claim that this placement of the principal's office signifies the role of the administration at the school. They recall that the principal of Norville Central for 20 years, who retired eight years ago, prided himself on being able to wander the halls of the school without being recognized. He believed in a de-centralized system in which teachers played an active role in shaping their school and he was principal for enough years to root those concepts firmly in

both the physical and social structures of the school. Some teachers feel now that the old democratic procedures are giving way to a more centralized system of administration creating some tension between administration and teachers.

Norville faculty are distinctive in the degree to which they prize their autonomy and take pride in their expertise. Of the 205 faculty members, 10 have doctorates and 160 have MA degrees. Most have been at the school for many years, partly a reflection of declining enrollments and budget cutbacks in the wake of a tax cap, mandated by the state five years ago. One department chairperson complained that he had not hired any teacher other than a temporary replacement for 10 years; administrators and teachers debate each year how to further cut faculty to stay within budgetary limits. Most of the faculty became teachers during the 1960's and many reflect the liberal values that drew many young people into teaching in those days.

Sustaining intellectual vigor among this stable, veteran staff is a source of concern to teachers and administrators. One response to this challenge is a careful rotation of course assignments and administrative duties among teachers. Department chairpeople devote enormous time and energy to devising schedules that provide faculty with a range of courses and of students from various grades and ability levels. Teachers are not permitted to teach any course for more than three years. Some teachers complain that the rotation policy keeps them from offering their favorite course, but most appreciate being forced to confront new challenges for the sake of their own rejuvenation and a democratic distribution of "plum courses".

The syllabus for a given course is determined by a curriculum team comprising the faculty who teach they course. Their process is typically democratic for this school. A veteran teacher of the course is made the team chairperson and drafts a curriculum which the others review, revise, and approve. The team meets regularly during the year to discuss their courses and to collaborate in developing examinations. Curriculum team chairs meet with the department chairperson to determine curriculum for the entire department. Many of the faculty teach from texts they have helped to write and have degrees in their subject matter rather than in education. Their self respect is reflected in a one-page statement of philosophy, developed through a long process of debate among the faculty, which says, "crucial to the success of our efforts is the freedom to teach unhindered by bureaucratic constraints and intrusions."

Given these circumstances, the academic success of Norville Central students is not surprising. Approximately 76% of the graduating class of 1983 went on to further schooling, 58% to 4-year colleges. Those students in the 1983 class who took SATs averaged 37 points above the national average on the mathematics section and 25 points above on the verbal portion.

Mobilization for the Laboratory Site Project

After ETC staff consulted the superintendent about he laboratory site project, he asked the school principal to convene a meeting with the relevant department chairpeople and any others she thought ought to consider whether the school should participate. After hearing the project description, the Norville principal expressed measured, but solid, support so long as it served the full range of students and recruited teachers carefully without infringing upon their prerogative to decline. She asked the library media specialist to serve as project liaison, because the school intended to estabish a computer laboratory in the library anyway under this person's direction. The chairpeople of the mathematics, science, and programming departments also expressed interest in the project and offered to present it to their faculty members. Within a few weeks, a total of seven teachers had ageed to participate, including three teachers who had formerly collaboarated on ETC research projects.

Preparation of the computer facilities should have been relatively smooth despite the large size and complexity of the Norville school system, because the school had already planned to create a computer laboratory in the library. Political battles over space, equipment, preparation of facilities, and ownership of turf had already been waged internally. Despite all of this advance work, preparation for the laboratory site project required the liaison to call upon all of her considerable knowledge of the school (she was a veteran staff member), her technical expertise, her extraordinary diplomatic skills, and her enormous dedication to the project. She found herself cajoling workman whose contracts stipulated very precisely how and when they worked, negotiating with irate faculty members who wanted to use the facilities simultaneously, inventing ways of preserving the delicate science apparatus, and quelling the objections of people who were aghast at water in the computer laboratory. Without her multiple talents, the laboratory project would have run aground in an unusable computer lab.

One part of the liaison's job involved facilitating negotiations between ETC and the Norville lab site participants who regarded the project with a certain wariness. The school people had participated in many university collaborations in the past. They wanted to be sure that ETC made good its promises about providing equipment and stipends. Subsequent exchanges revealed that the suspicious atmosphere also reflected the faculty's professional confidence and concern that their expertise might be underestimated.

Geometry Innovation

Planning and Early Impressions and Mobilization

Mira Stillwell, the chairperson of the Norville Central math department, had purchased the *Geometric Supposer* before the laboratory site project was initiated because she thought it might improve students' "spatial thinking", a crucial but underemphasized aspect of geometry courses. Yet she found that this software "did not take kids somewhere on its own". Not sure how to use this promising tool, she found participation in the laboratory site project a very attractive proposal.

Mira wanted Amy Donalds, who had moved to Norville Central from a junior high school a relatively recent four years ago, to experiment with a new course or teaching method in the up-coming year. Amy recalls she was "still only 50/50" convinced after the initial meeting about the project, but thought the approach sounded more interesting than the typical "dry and boring" geometry course. Judith Hurley, a third Norville Central math teacher asked to join the project because she felt "totally burned out" and thought the *Supposer*-based approach would refresh her professionally.

Mira thought this combination of three teachers would offer an excellent opportunity to test out what the *Supposer* could do, as all had different teaching styles, different personalities, and would be teaching different grades and levels of geometry student. Mira's enthusiasm reassured the other two. They all took computers home during the summer to begin studying the *Supposer* software.

Implementation Process

Norville North's unusual math program offers a two-year sequence of combined algebra and geometry courses. Most students take the first year as ninth graders and the sequel the following year. Most core courses at Norville Central are tracked according to the students' academic level: general courses are taught to students who do not expect to go to college, curriculum II courses are for less accomplished college-bound students, curriculum I courses for those who have demonstrated more self-discipline and achievement, and honors courses for especially able students.

The lab site teachers taught different courses from this array. Amy taught Algebra/Geometry I to a curriculum 1 class whom she described as "very average, college prep. students, not interested in exploring". She thought they had to be "directed step by step and [couldn't] handle open-ended problems". She believed that curriculum 2 students would have been able to deal

better with open-ended assignments. Mira had an honors class of ninth grade students whom she regarded as "very bright" and able to explore complex, abstract problems with discipline and creativity. Judith taught Algebra/Geometry II to curriculum 1 students, most of whom she saw as competent and fairly motivated.

Given their various agendas and starting points, the three teachers began their courses in different ways. Both Mira and Amy began with algebra and did not intend to start teaching geometry until 8 or 10 weeks into the f^11 term. Judith, on the other hand, taught students who had already taken a geometry course. Whe: she started geometry work during the first few weeks of the term, her students already had a foundation of knowledge about geometry.

Judith was amazed by the ease with which her class dived into the *Supposer*. "I'm sold," she reported at a meeting of the Geometry Group in October. "I didn't go over the menu with my kids or anything. They just took off!" Almost immediately she began to teach a unit on similar triangles, as part of a teaching experiment conducted by the ETC Geometry Research Group. The unit involved several weeks of carefully specified lessons which were closely observed by the research staff. Judith found the experience to be very demanding, pulling her and her students quickly and deeply into a radically different approach. With regular consultation by the researchers, she assigned problems to her students which they studied with the *Supposer* during lab sessions. Then she led discussions about the students' findings, constructing inductively the knowledge of geometry that she had previously taught, with great delight, through a formal, deductive approach. By November, her early enthusiasm was tinged with concern as she pronounced this approach "revolutionary".

> I'm coming to see that my interest in geometry focused on the beauty and self-contained completeness of a deductive system. With the *Supposer*, that is no longer the focus....Our class discussions do show that kids are really thinking. And we've already had Driscoll's [a student's] theorem. One kid who said almost nothing in class this year turns out to be an excellent mathematician. But we're postulating all over the place; we've dealt with more postulates in a week than I used to use in a month. If one is in love with a truly deductive system, this is heartbreaking....And I worry about the final exam. This approach requires a leap of faith. I do think the kids are learning more and better meathematics, but it's hard to give up my safe way of teaching that I'm familiar with.

As department chair person, Mira reassured Judith that they would devise an exam tailored to the course she had taught. While this may have alleviated some of Judith's concerns about putting her students in a competitive position with other classes, her remarks conveyed the fundamental anxiety of a teacher forced to reconsider the whole structure of her subject matter, the goals of her course, and the process of teaching and learning.

Mira took several weeks to prepare her students to use the *Supposer*, being careful to establish the relationship between it and other geometry tools. She helped students develop definitions of geometric concepts by exploring constructions with the *Supposer*. She found they quickly became adept at gathering data and generating conjectures. Mira collected all students' conjectures, reproduced them and distributed them to students, then used these collections as worksheets for discussions and for generating proofs. Thus students produced "their own food for thought", obtained a clear picture of where things came from that they bothered to prove, and learned to see themselves as generators of mathematics. While Mira felt these were clear benefits, she shared Judith's concern about "covering the curriculum". Mira struggled to bend the conjectures produced by the students to address the department's standard curriculum.

Amy also struggled to link her students' findings with her own agenda and found that the task required her to alter the way she used her text book. "In the beginning I felt guilty if I didn't use the book, so I tried to organize the *Supposer* lessons around the topics in the book." For instance she'd teach a lesson with the *Supposer* in the lab and then assign homework from the book. She felt guilty partly because it was a new text and not using it would be a waste. The text also legitimated the course content. "I thought it would give the students a sense of security, and me too. The kids need structure."

As Amy became more accustomed to teaching inductively with the *Supposer*, she found that the book often did not present topics in the right sequence for her lessons. She began to use the text only for homework assignments, but by the end of the year said,

> Now I don't feel I need to use the book. I organized the congruence unit myself....The book presents the three congruence postulates, then has kids do simple proofs, then adds a few theorems and finally presents CPCTE [corresponding parts of congruent triangles are equal], a major proof. With the *Geometric Supposer* that wasn't the right sequence. You could go from the postulate directly to CPCTE. [This was] much easier to teach, and an easier sequence for the kids to understand....I don't feel guilty now. I've looked through the book, through the chapters, and I'm comfortable that I'm covering all the materials, maybe in a different sequence, but eventually we get to everything."

Teaching in this way was not easy. Amy noted that her course was not as structured as the usual course where you go "page by page through the text" and can "plan by the week". With the *Supposer* you "wing it day by day" and it requires a lot more flexibilty as a teacher. "Every time I start a new topic, it's nerve-wracking. Not knowing where the lesson will go, how kids will react to a work sheet creates a feeling of insecurity." Teaching with the *Supposer* a second time would be considerably easier, Amy surmised, because she would understand better how to structure lessons to build students' understanding.

This difficulty in anticipating how students would respond to the new lessons and approach created problems around scheduling time in the computer lab. The computer laboratory provided by ETC for this project was the only set of microcomputers available to Norville Central teachers and students except for programming courses. Consequently, the geometry teachers had to share the lab with each other, as well as the science teachers, and other faculty who became increasingly interested in discovering how they might use computers. The geometry teachers found they could not anticipate in advance exactly when they would be ready to teach a lab-based lesson nor exactly how many class periods a lesson might take. Yet the lab had to be reserved well in advance in order to accommodate all the teachers who wanted to use it. The Norville liaison, who took responsibility for coordinating all the requests for the computer lab found, "to please one person, I had to disappoint a lot of others. But, I suppose it is very good to work with a faculty of people who have that level of commitment."

Grading students was also a challenge. Part of the difficulty was to design a way of grading that reinforced students' progressive mastery of inductive reasoning skills. Mira developed an effective strategy. At first Mira didn't grade labs, but explained to students that they were responsible for learning to use the *Supposer* as a tool. She collected three things from students for each lab: data, conjectures, and formal proofs. They received 1-3 points for producing each. At first she told them she didn't know how this would fit into their overall grade, but they should try to get mostly 2s and later 3s. Eventually she decided to count the total of all lab points as equal to one test. On the term test one question involved *Supposer* work on the computer. She found this approach was sufficiently clear to focus students' attention without making them excessively anxious about grades.

In coping with the problems and uncertainties of integrating this new approach into their courses, the Norville geometry teachers found they turned mostly to each other. They thought it was essential to have had computers, software, and problems to work with over the summer before they attempted teaching with the new materials. The problems and materials supplied by the ETC staff were helpful, but the teachers still had to select and modify particular problems for their classes. Amy found the advisor to be very helpful in selecting problems and designing a *Supposer*-based teaching unit. "But a lot I had to discover myself. It takes a lot of time to figure out what to teach and how. It's important to try out a worksheet before you give it to the kids." Actually working through a problem before she gave it to students helped her identify typing mistakes or other potential sources of confusion, learn whether the sheet provided enough room to record the necessary diagrams and other data, and anticipate what students might find or ask. All of this required hours of preparation in the evenings and on weekends.

Norville teachers thought that meetings with other laboratory site teachers were not always very helpful. Talking with other teachers about specific units they had taught and learning how students reacted was useful, but the more general discussions were not. "Our style is not to just accept materials", Mira noted. In keeping with their school system's reputation, these Norville teachers wanted to develop their own problems and strategies. For the most part, they preferred to manage by consulting with each other, rather than attending meetings where, according to Mira, "Norville teachers are usually giving and not doing much receiving."

Impacts

While the three teachers varied in their assessments of the impact this project had, they were all very pleased with its results. The variation in their views appeared to reflect differences in their teaching styles as well as differences in their courses and students.

Teachers thought this approach to teaching geometry was more fun for most students, enhanced their skill and confidence in thinking mathematically, and, for some students, increased their knowledge of geometry more than their traditional approach. Mira thought the main impact of the *Supposer*-based approach lay in its integration of inductive and deductive reasoning. The *Supposer* presented both visual and numeric data that students analyzed for patterns in a way that "brought mathematics to life....Proof was not that heavy thing; it was the tool we use to sort through all the conjectures to see what things were really true." Amy thought the *Supposer* was particularly useful for her average students who "need concrete experiences". The *Supposer* was akin to the manipulative materials she regularly used with junior high school students to make abstract ideas into real objects that students could construct, examine, and control.

The experience of working with mathematical data, developing their own ideas, and evaluating student-made conjectures gave most students a much more positive attitude toward mathematics. Judith reported, "I think that sense of having some control over one's learning experience and being able to do mathematical discovery made [students] feel that they could do mathematics." Amy echoed this sentiment, "I can see a big change in their attitudes toward math. They don't feel quite as frustrated or as threatened. They are really very open and confident. Even if they don't get everything perfectly correct, it's not as threatenting now as it has been in the past."

Both the teachers and some students worried about the impact on the traditional curriculum. While they believed the new approach addressed important goals (such as learning how to construct geometry inductively) that were neglected by the traditional curriculum, they also thought the

Supposer innovation crowded some topics out of the old curriculum. All three teachers worked to integrate the old and the new, using the inductive, *Supposer*-based approach to teach some important topics in the traditional geometry curriculum. They found it not an easy process, however, as evidenced by Amy's description of her reorganization of her lessons on the proof about corresponding parts of congruent triangles. Further efforts to achieve an effective integration will constitute part of their work in the coming year.

This approach altered classroom interactions and roles in significant ways. At one level, the shift from traditional lecture-style classes,which typify most mathematics courses, to classes in which students worked independently or contributed to a whole class discussion required a significant change in routines. Teachers had to invent ways of distributing and collecting assignments, of moving among students as they worked to guide their inquiry, and of conducting discussions that interwove students' ideas with the teacher's agenda.

In making this transition, teachers are aware of a shift in control from them toward their students that must be managed in order to produce effective learning. While they expressed some concern about retaining sufficient control to accomplish their agenda, these teachers felt the shift was primarily very positive. Amy said, "I established a different relationship with my kids. The kids were more enthusiastic...more friendly on a personal level. In my other classes there is more of a teacher/student distance...This has placed a lot of responsiblity on the students for their own learning...It really has been fun." In a similar vein, Judith reported that the *Supposer* innovation helped her establish a closer relationship with her students, both because she was able to work with them individually during labs and because the entire class shared their ideas. The work belonged to students and teacher in a way that it does not in a traditional class where "the work is imported via the text or the teacher....It's odd to think that the computer would increase the quality of human interactions in class, but that's true," Judith concluded.

The teachers also felt that, although the project had been intensely demanding, it had been a powerful professional refreshment. Judith said she had felt "totally burned out" before beginning this project and knew she was in need of a change. This project replenished her interest in teaching. "I'm so excited about what I'm going to be able to do next year." Amy cautioned that she had worked very hard and dealt with a lot of frustration and insecurity, but "It's been fun....and it really has made me enjoy my job much more so than in the past. It's really changed my outlook in terms of going into school, working with kids."

Near the end of the year, Mira organized a presentation to the entire math department at Norville Central, where she and the other two teachers described their work on this project. She

invited other teachers of geometry to teach with the *Supposer* next year. The three experienced teachers offered to serve as advisors to their colleagues. By the end of the school year, teaching schedules were reaching final form, and Mira reported that many of the geometry teachers at the school wished to work with the *Supposer*, at least to a limited degree. All three lab site teachers planned to teach with the *Supposer* themselves and also to work as advisors to colleagues who taught parallel courses.

Science Innovation

Planning and Early Impressions

Gerald McCurdy had used computers for demonstrations in his classrooms for six years before he became involved with the ETC Research Group on Heat and Temperature when it formed in 1983. As a member of that group he helped develop the materials ultimately used in the science strand of the laboratory site project. Gerald had also helped supervise the pilot-testing of these materials during the spring of 1986, by two of his fellow science teachers at Norville Central High School. Gerald was interested in the lab site project for several reasons. He wanted to help make the results of the the Heat/Temperature Research Group's work available to other teachers. He also looked forward to using the materials with his own students, expanding his customary use of computers from a tool for demonstrations to a tool to help students gather, analyze, and interpret experimental data. "This gave me a framework for working individally with students," he said.

Ronald Davis, another science teacher, had somewhat different motives. Although he had taught at Norville Central for 11 years, and had taught college physics before that, he faced teaching freshman physical sciences for the first time. The ninth grade had been added to the high school only four years ago and the rotation of course assignments had finally brought Ronald and this course together. As a teacher of upperclassmen and college students he had concentrated mostly on content rather than teaching methods, but he thought the younger students might require him to pay more attention to pedagogy. He thought the lab site science lessons might offer an effective approach, more likely to engage ninth graders than the science textbook. The usual science course, Ronald complained, "is all verbal". Information is "thrown at students" who can only interpret it as "a fairy tale". The textbook he used introduced heat as the "capacity to do work" and temperature as "average kinetic energy". While students might memorize these definitions and repeat them on tests, Ronald thought the words had no meaning for most students and remained unconnected to their daily lives. He hoped the lab site lessons would help overcome this problem.

Ronald recalled that his interest in the lab site project was enhanced by two things. First, knowing that his colleague had helped design the materials made him more confident that they would be suitable to his classes. Second, he appreciated that teachers would be paid for their participation. He thought teachers were too often expected to contribute their expertise, *gratis*, as trainers of student teachers for instance, and believed such practices did his profession a grave disservice.

Implementation Process

Four of the lessons given to lab site science teachers were based on experimental lessons developed by the ETC Research Group on Heat and Temperature using Microcomputer Based Laboratory equipment to help students distinguish between heat and temperature. The teachers also received materials for eleven other lessons that used MBL thermal equipment. The latter were edited versions of lessons originally designed at Technical Education Research Centers (TERC) for middle school students. They were conceptually simpler and broader in focus than the ETC-developed lessons. Finally, the teachers received software and worksheets (designed by Gerald McCurdy) for two lessons that enabled students to work through simulations of two experiments: one focused on specific heat of different materials and the other on latent heat as indicated by cooling curves.

All of these lessons were designed as experiments to take place in a computer laboratory where students would work individually or in groups of 2-3. Lab site teachers selected from among these materials depending on their students and curriculum requirements. It was assumed that teachers would intersperse these sessions with other classes designed to introduce the lab exercise or help students make sense of their findings.

Gerald used the lab site science lessons with his three chemistry classes (all curriculum 1 level courses) and, in a slightly different way, with his honors chemistry class. Gerald characterized his students as "conscientious about homework, above average in math competence, and they have the self-discipline to work during class." In Gerald's view, the ETC lessons were more difficult than the TERC lessons. The ETC lessons were "too sophisticated for students below curriculum 1" and would be more broadly useful if they were simplified and edited. The TERC lessons were briefer, less demanding intellectually, and better suited to short class periods and less able students.

For his chemistry classes he designed a two week (10 class period) unit on heat and temperature, that included all the ETC lessons as well as his simulated experiments. During this time he taught 7 of his lessons in the computer lab, whereas he normally taught only 2-3 labs per

week. Thus the lab site innovation was slightly more "lab-based" than his usual approach. Unlike, some other lab site teachers, Gerald had two double periods scheduled for lab sessions each week. He thought the double periods were not essential, so long as a teacher was careful to schedule a pre-lab and post-lab class between lab sessions. He acknowledged, however, that 45 minute periods made teaching complicated labs very difficult, especially with less able students who have more difficulty remembering things from one class to the next.

In designing his lesson sequence, Gerald was constrained by the amount of time he thought he could devote to thermal pheonoma. He teaches according to a curriculum that he works out with the other teachers of the same course. Their syllabus takes into account the College Board Examinations and the chemistry achievement tests that many of their students will take at the end of the course. Having developed the curriculum in this way, and given the necessity to prepare students for these tests, he felt responsible for sticking close to the syllabus. He regarded it as "tightly set with perhaps 1-2 weeks of flexibility, but certainly not a month." He thought the situation was approximately the same for biology and physics, but a little different for ninth grade physical science. Because students do not take a standardized test after this course, Gerald thought teachers felt more flexibility in modifying its syllabus.

Like Gerald, Ronald taught all four ETC-developed lessons to his classes as well as the simulated lab designed by Gerald. Ronald found that "the ideas were fine" but these lessons were not well-tailored to his ninth grade physical science students. He discovered that "you need smaller pieces for ninth graders" than these lessons provided or than he was accustomed to teaching to upperclassmen. Lessons had to be simplified and more structured for younger students. Because he was not familiar either with these students or with the lessons, he did not always anticipate correctly what would seem confusing or boringly simple, and he found it difficult to adjust once his students were in the lab.

Like the geometry teachers, the science teachers had to convene their computer-based lessons in the computer laboratory several corridors away from their regular classrooms. If a lab-based lesson finished faster than expected, there was no convenient way for students to use the remainder of their time on projects back in the classroom. Ronald found geographical gap tended to impede his ability to integrate computer-based lessons with the remainder of his course.

The project liaison at Norville Central also wished that the science teachers could have used a computer lab in their own department. She recruited another assistant to help her and the science teachers set up equipment for these lessons and be available for trouble-shooting during classes. The science lessons required fragile peripheral devices and a great deal of related equipment.

Housing all this safely in the computer lab was inconvenient. She concluded that the safest policy was to ban other classes from using the computer lab during the two-week period when the science classes taught their heat/temperature lessons. Her decision annoyed other teachers who were temporarily denied access to the computers. Owing to the liaison's tact and effort, this difficulty was sorted out, but it is typical of the logistical tangles that plague such innovations in their early days.

Impacts

Gerald "considered the experience successful for me and my kids...It gave me joy to see students using the simulations I designed." He liked doing research on his teaching and enjoyed participating in a research effort. He believed that the individualized approach for students and the intense involvement in the subject matter over a short time period were valuable. The rapidity of calculations reduced tedium. He thought the graphical displays of temperature change as a function of "dollops" of heat emphasized the difference between heat and temperature so that the experience was "richer", although he wasn't sure students actually learned more. Ronald found this way of teaching about heat and temperature "1000 times better than the text" book lessons on this subject. He thought the text presented this topic in a way that most students found meaningless.

Neither of the Norville Central science teachers felt that they radically altered their classroom practice due to the lab site innovation. They were accustomed to teaching science labs. The computer just added one more layer of complexity to the apparatus that must be set up. Teaching style and the relationship between teacher and student were little influenced the Heat and Temperature innovation. Gerald did not see the lab-site lessons as inductive, remarking that "I present a problem and then the students work it through....It's mostly deductive because of the time constraints. We do look at data in labs sometimes, but that's a small proportion of times because it's very time consuming." He would have liked the software to be more open-ended because, as currently structured, he did not feel that it allowed much exploration.

Both teachers thought the materials needed further development. The ETC-developed lessons were too advanced for many students and needed to be edited and simplified

In assessing the overall costs and benefits of the science innovation, both Norville Central science teachers tended to focus more on their potential impact on learning rather than on their current teachability. They paid relatively little attention to the breakdowns and other logistical problems with apparatus, which preoccupied teachers in other lab sites. This may reflect the amount of help they received in conducting their labs from the project liaison and lab assistant

provided by the science department at Norville Central. Their focus was also consistent with a general pattern among Norville Central faculty which was to concentrate more on subject matter than on the logistics of teaching.

Programming Innovation

Planning and Early Impressions

Both Kim Houghton and Peter Skinner brought extensive experience to the programming strand of the ETC laboratory site project at Norville Central. Each had taught programming for nearly 20 years and had worked collaborated with the Educational Technology Center since its establishment.

As computer coordinator at the secondary level for the Norville Public Schools Peter planned and supervised all computer-related programs at both Norville High Schools. Peter had also served as a member of the ETC Programming from its inception. His participation in the group's research and early development of the metacourse was sporadic, primarily because his responsibilities at school and his many other intersets outweighed what he regarded as the questionable benefits of ETC's research. As a former educational researcher he was skeptical of the payoff of university-controlled research. Meanwhile, the demands of administrative and teaching responsibilities at school were always pressing. While ETC had not been at the top of his priority list, the lab site project attracted Peter's interest. He enjoyed teaching programming because it is a creative course and "one of the most intellectually stimulating subjects, incorporating both the abstract and the applied." The ETC project provided an occasion to reevaluate the computing program, something Peter and other programming teachers in Norville had been wanting to do, in conjunction with a group of researchers who shared their concerns. "Both Kim and I were very interested because we had been looking to do this on our own for a long time."

Like Peter, Kim Houghton was no stranger to ETC. As a mathematics teacher she had participated in several ETC mathematics research projects. She was also the kind of teacher who continually questions what and how her students are learning. As a contemplative educator, she was eager to try a new approach that promised to offer improved lessons for her students. In keeping with her typical approach, Kim came to the Introductory Conference in June, 1986, having already read and thought about the metacourse materials. She came prepared with questions and suggestions about ways of making the lessons clearer and more consistent. "I do my homework," was her understated self-characterization.

At Norville Central introductory BASIC is an elective course, the first in a sequence of computer science courses, with an algebra prequisite. Kim taught an honors section, and Peter taught a Curriculum I or college-preparatory level section. The classes were mixed by grade level, but most students were tenth or eleventh graders. The teachers met with their classes twice a week in a regular (i.e., without computers) classroom. The Norville schedule allowed the students enough time out of class to work on assignments on the school's DEC PDP computer.

No required curriculum for programming was set by the department at Norville Central. Instead, a suggested syllabus and sequence of problems, developed by four Norville teachers several years ago, provided an informal set of guidelines for programming teachers.

Implementation Process

The initial stages of the metacourse went very smoothly in both Peter's and Kim's classes. Both teachers moved quickly through the first half of the Metacourse lessons, more speedily than teachers in other lab site classes. Kim rightly perceived that the Research Group hoped lab site teachers would regard the tightly scripted lessons as examples to be modified as necessary by teachers to reflect their own wisdom and style and to serve their students needs. She incorporated the metacourse Computer World--a diagrammatic model of how elements of computer technology function--into an approach she had successfully used in the past to show students how the computer's memory, screen, and program interact. Peter also adapted the Metacourse scripts to accommodate the interactive way he and his students usually wrote and debugged programs in class.

Observers from the ETC Programming Research Group noted that the students in both teachers classes appeared to be very able and to encounter few problems with the metacourse lessons. The teachers were able to integrate most of the metacourse lessons into their regular course agenda without significant difficulty. One of the metacourse lessons was particularly long and cumbersome for most of the lab site teachers. Kim successfully combined it with a large project she customarily assigned over several class periods. After examining the lesson closely, Peter abandoned it in its Metacourse form. He realized that his regular curriculum already addressed several key elements of this particular Metacourse lesson and decided to rely on his own comfortable, tried-and-true approach. The Norville teachers were unusually able to exercise their own judgment in discerning and implementing the spirit rather than the letter of the highly specified metacourse.

Impacts

Before teaching the metacourse, Kim had wondered whether it would offer much benefit to her class of honors students whom she expected would learn well even without excellent instruction. In fact, she reported that some of the students were "insulted" by the easiness of the problems in the early lessons, although her weaker students and foreign language students liked them. She was pleased that some of the later Metacourse lessons appeared to help all the students. What was particulary useful was that the Metacourse identified certain useful patterns of code and then assigned these patterns memorable names. She noted that students regularly referred to these patterns in the Metacourse materials and seemed to make good use of them in writing well-structured programs.

While Kim believed the Metacourse patterns helped her students, she thought the overall impact of the metacourse was not radical. Honors students in her introductory courses had usually emerged as good programmers, even without the Metacourse. The Metacourse had helped her recognize and present some concepts explicitly that she had previously taught less consciously. Offset _ this benefit was the fact that fitting the Metacourse lessons into her course was accomplished by eliminating a project she and her students had always enjoyed.

Like Kim, Peter perceived that the Metacourse lessons had helped students grasp some difficult, abstract concepts in programming by making them more concrete. The benefits of the Metacourse itself were difficult for him to assess because he thought his students had been unusually able, "one of my best classes ever." He credited their success in his class to their own abilities, his improvement as a teacher, and to the metacourse materials.

The teachers thought they themselves had benefitted from the Metacourse. Peter, for example, said that the Metacourse materials which help students distinguish between a programming statement's purpose and ·ion clarified a common sticking point he had not previously recognized as confusing. Once this difficulty was revealed, he was able to amplify the Metacourse strategies to help students overcome it. In general, Peter perceived that the Metacourse offered a general *approach* to teaching programming which must become part of a teacher's regular repertoire "I don't see the metacourse as something which you can just break into eight pieces and plug in for eight days. What you really need to do is understand the philosophy of the metacourse and then incorporate that into the way you think about teaching that material."

Kim also found that the Metacourse offered "an extension of the same ideas that I had been using in teaching programming." It "fit very closely with what I normally did" and was therefore easy for her to incorporate into her classes. She had two, relatively minor complaints. First, she was unaccustomed to using the overhead projector (Metacourse lessons employ a large number of slides developed for this technology). Second, the Metacourse involved a large amount of paper, including extensive materials for both students and teachers. Kim found these cumbersome to carry to and from her programming classroom which is some distance from the place where she teaches her other classes. In Kim's view the metacourse more than compensated for these minor inconveniences, by giving her an opportunity to think more about how to get the most out of her teaching approach

Both teachers felt that they would use the metacourse concepts in their own teaching in future years. Peter thought it would be worthwhile to meet with all teachers of programming to review ways of incorporating the most useful parts of the Metacourse into their practice and curriculum.

Willis

The School

Willis High School beckons visitors to the front entrance with a large American flag visible as they turn into the long driveway bordering the huge playing fields in front of the school. Repeat visitors tend to use the more convenient side entrance, as the superintendent does on his frequent trips over to the high school from his office in a wing of the elementary school a short walk up the hill. Both entrances lead down a short corridor to the principal's office, where visitors are encouraged to check in with the school secretary. She knows everyone's schedule, not only their planned agenda, but daily news that alters regular routines. Between answering the telephone, delivering messages to students and teachers who stop in, and making all-school announcements on the loud speaker system, she queries visitors about their business and directs them to their destinations. She uses the intercom connected to every classroom to track down staff members before sending a visitor along to meet them.

Lab site staff found they often bumped into the principal in the hallway before they reached the main office. He can often be found at the intersection of two main corridors outside his office. From that vantage point, next to the cafeteria, he can take the school's pulse and conduct quick conferences as students and teachers pass between classes. Indeed, a good deal of business at Willis High School is transacted in the corridors rather than during scheduled meetings. The single story building is compact. Its main corridors in the shape of an "H" bring the schools' members and visitors together at a few busy intersections. Arrangements that might take several telephone

calls and synchronized appointment books in many schools can often be accomplished at Willis High School between classes or in the faculty lounge where teachers get their mail, use the copy machine, have a cup of coffee, and eat lunch.

The town of Willis is located approximately 75 miles west of Boston, too far for commuting yet near enough for many townspeople to identify with urban Eastern Massachusetts rather than the more rural Western part of the state. Through the mid-1950's Willis was a thriving mill town, with bustling textile mills and shoe factories surrounded by productive farm land. In those days, Main Street boasted clothes stores, family businesses, and a movie theater. It was the social as well as economic center of the community. Young people in Willis tended to stay on to raise their own families. Many of the teachers and administrators in the Willis schools were graduates of Willis High School and nearby colleges.

Then the bottom dropped out of the mills in the late 1950s, and through the 1960s the town began to decline. Some people left; others found jobs in the insurance businesses in the largest nearby city or in the factories of neighboring towns. Recently, Willis's relatively low cost of housing has attracted a number of new residents with low incomes. At the same time Willis has become a bedroom community for a new population of professionals who commute to jobs in surrounding cities. Long-term residents complain about the rush hour traffic jams on streets that used to be quiet. They regret that old Willis families are not reseeding themselves in the town, but understand why they leave. "The young people who go away to school don't come back," remarked one resident. "Why should they? There's nothing to do. We didn't even have a movie theater after it burned down 15 years ago until just recently they reopened it." While the total population of Willis has remained around 8,000 people, the composition is changing.

Life in the Willis schools has not changed damatically over the years. Enrollment has remained around 1300-1500 during the past seven years. The system includes one elementary, one middle, and one high school. The High School enrolled about 450 students during the 1986-87 year in its four classes. A current teacher who graduated from Willis High School 40 years ago said students have not changed much since his time; interest in sports and proms is still much greater than in colleges and careers.

"Limited aspirations" was the phrase school people used most often to describe the educational values of Willis parents and students. "The mentality of most of the people here is that they go to work to earn a livelihood...they raise their kids to stay in Willis and do the same thing," said one teacher who also complained that few parents came to school meetings or volunteered to serve on committees. Another conscientious teacher regretted that many of her students showed

little motivation to complete their work and would drop out of a course entirely if they missed too many days to earn credit for the course. "Don't aim too high," was the message several teachers interpreted from the community's treatment of its schools.

Despite these concerns and beliefs, one half of the graduating seniors continue their education beyond high school. Of the 122 students who graduated from Willis high school in 1985, 31 went on to 2-year colleges and 30 to 4-year colleges.

Staff and faculty at Willis High School tend to stay. "Even the cafeteria help has been here for 10-20 years," one veteran remarked. Most of the 35 faculty members have been at the High School for over 15 years; only four new teachers were hired in the last eight years. Eighteen faculty have MA degrees and one has a Ph.D.

Although the shift in residents had not yet had a major effect on the students in Willis schools, the superintendent anticipated a change in the near future. The 1980 census showed that only 56% of Willis's adult residents had completed high school and only 8.7% had finished college. The superintendent expected, however, that many of the new residents in Willis would be more concerned that the High School prepare their children for college. Even the older residents, who were themselves content to remain in the community of their parents, want their children to gain the skills necessary for moving into a larger and more complex world.

Under these circumstances, the superintendent was very glad to join the ETC consortium. When he was promoted from being principal of Willis High School to the superintendency in 1982, one of his goals was to "get Willis into the computer world and not make mistakes doing it". More generally he wanted to see teachers exposed to new ideas and approaches. Teachers and administrators at Willis commented on the enthusiasm generated by having someone like ETC staff from "out there" (meaning "non-Willis") pay attention to the town. The superintendent said that "the stranger with the briefcase" was almost always viewed as a positive occurance by both faculty and students who felt remote and unrecognized. One teacher, who had returned to Willis after a long absence, said, "Anyone who has lived and worked in the world beyond Willis is considered an expert when he returns."

The high school principal was also supportive of involvement with ETC, particularly the laboratory site project. Asked about the most important part of his job he replied, "To encourage teachers to keep changing. There is very little change in faculties now and it's easy to stale." While he was in favor of Willis's participation in ETC, the earlier years of the project had seemed "very theoretical". Willis teachers traveled to Boston for research meetings, but they brought back

few results. "We felt sort of like the poor cousin who lives 100 miles away and sees the family only on holidays," the principal recalled. He was very enthusiastic about the laboratory site project because it promised to bring computers and classroom materials to the school along with advisors to help teachers incorporate the new technology into their lessons.

Mobilization for the Laboratory Site Project

Based on their enthusiasm for the lab site project, the superintendent and principal invited the lab site project director to address the science and mathematics faculty. At the meeting, the principal announced his appointment of a liaison for the project. This man had recently returned to his home town after retiring from a successful career in New York as a school principal, and had taken a part-time job teaching mathematics at Willis High School. The liaison said he viewed the ETC lab site project as a good opportunity to get more computers into the school and integrated into the regular curriculum.

Two geometry teachers were very eager to participate in the lab site project. They worried that ETC would not include the school unless the other strands were also implemented. The programming teachers agreed, but the only science teacher who was interested in using computers did not teach a course that could reasonably include a unit on heat and temperature. Given the eager commitment of the Willis project participants, the Willis site was included despite the the lack of a science strand.

Arranging facilities and logistics for the lab site project was relatively simple. Preparations that required politically delicate negotiations in other school systems, were accomplished easily and informally in Willis. The liaison reported:

> When it came to electrical outlets, for example, I spoke to the principal and he said, "Just call Bernie at the shop. Better still, Bernie is supposed to come in this afternoon, so why don't you just mark on the wall where you want the outlets to be." And in a week the outlets were there.

The computer laboratory facility at Willis was completely prepared and outfitted by the time the computers were delivered from ETC at the beginning of October. The computers, originally been promised for the first of September, were delayed in shipment. This delay had no effect on the programming teacher who had a full set of computers in her classroom. The geometry teachers, in retrospect, appreciated the first month without computers, because it gave them some time to introduce the *Supposer* slowly to the students (via a single computer with a large monitor in the geometry classroom). Still, the whole school anxiously awaited the machines, at least in part because they represented a prestigious, tangible commitment from ETC.

When the truckload of computers finally arrived from ETC, all the lab site participants, the principal, and the superintendent gathered to celebrate and help unload them. Overall, the lab site project was welcomed at every level of the school system as an opportunity to bring modern technology and admired expertise into a community that felt undersupplied in such resources. This widespread enthusiasm, coupled with the relatively simple, integrated and small school structure, made preparation of lab site facilities, equipment, and schedules a comparatively smooth matter.

Geometry Innovation

Planning and Early Impressions

Pamela Olson, chairman of the mathematics department at Willis High School where she had taught for more than twenty years, first heard about the *Geometric Supposer* in 1984. She attended several professional conferences each year with enthusiastic encouragment from her principal. At a regional conference for math educators she heard Judah Schwartz, one of the *Supposer* developers and Co-Director of ETC, describe how the software could be used to teach geometry. Her colleague, Beverly Lewis, recalled, "Pamela came back and told me, 'You're not going to believe how great this is.'" She decided to order the software for her department, because she thought it would help students understand geometry.

When the ETC laboratory site project was proposed in the Spring of 1986, Pamela and Beverly both eagerly agreed to participate. Neither teacher had taught with computers before. Pamela "was afraid of computers....I'd sat through an 8 week computer course without even touching a computer....We had one computer at school, but I hardly touched it unless someone was there to watch me and make sure I didn't break it." Although she had taught geometry regularly during her career and "always enjoyed it", Pamela had not taught the course for several years.

Beverly had seen a demonstration of the *Supposer* software and, though she had not taught with it, thought it offered a valuable new medium for teaching geometry. It would allow her to demonstrate concepts with accurate diagrams and "add a needed dimension of tactility" to geometry for those students who do not easily grasp abstractions. "Lots of kids don't respond to a lecture type or imaginative type of learning. This would give them more tangible, hands-on reinforcement to all those theorems and postulates. Bright kids get them, but struggling kids need something to really see and fiddle around with," Beverly said. Her interest in the *Supposer* contributed to her desire to participate in the lab site project. "We thought it would be great if we

were accepted into the project," Beverly recalled. " We ended up getting accepted and we were very enthusiastic about beginning it."

While many aspects of the software appealed to these teachers, the inductive instructional approach was radically different from their accustomed teaching styles. Their emphasis had been on didactic, teacher-led presentations to the whole class. Beverly observed:

> This was different from our usual way of teaching. We used to introduce vocabulary very formally, the written word, and the definition, and memorization of that. This year, with the *Geometric Supposer* we were able to [help students] develop some suspicions about vocabulary, then come up with formal definitions, find out why the definitions were good or not good, and this also taught them a little about what would be good in a conjecture.

The teachers had mixed feelings about the more open-ended approach they were encouraged to employ. On the one hand they thought it was valuable to teach students how to think in a way that was more exploratory and learn to "focus on the problem itself, not take tangents here and there". On the other hand they felt students who were not "top ability level" often could not handle open-ended questions. Furthermore, the teachers were not comfortable posing problems that might raise questions they could not answer. "If we don't understand the question, how can we guide the kids," Pamela worried.

Implementation Process

Both teachers taught geometry in the same classroom, at different periods. Geometry classes at Willis were not tracked so each class included students with a mix of ability and skill levels. Their classroom contained rows of chairs with broad arms for writing and two large teachers' desks at the front of the room next to the chalkboards. In one corner a rolling cart held one computer and a large monitor. Once the computers arrived from ETC, they were placed on tables arranged around the perimeter of the classroom.

In September, while waiting for the ETC computers, the teachers used the single computer as a demonstration device with the *Geometric Supposer*. They were both relieved that the computers did not arrive in time for the opening of school. During this period, both teachers used the *Supposer* and the demonstration monitor to introduce basic definitions in geometry. In the past, Beverly said, the beginning lessons in her geometry course introduced "an overwhelming" amount of vocabulary which was taught in a formal, didactic fashion. The teacher or the text presented a definition which students were expected to memorize. With the *Supposer*, the teachers were able to approach this task in a more constructive way. Working through the software menu with the class,

the teachers would demonstrate what happened when, for instance, "draw an altitude" was selected. Based on several examples they would ask students what they thought an altitude was. "I would allow them more input in developing vocabulary, coming up with a definition, and then finding out why one definition was good or not good," Beverly recalled.

In retrospect, Beverly thought she could have developed vocabulary in an even more inductive way. "I still stuck more with the traditional. We talked about possible definitions and then I wrote down the exact thing that I wanted. I didn't let them get any misconceptions on the vocabulary." At the end of the year when she understood more about the how to teach inductively, Beverly thought that developing definitions with students provided a valuable opportunity for introducing the reasoning processes they would later apply to evaluating conjectures and testing hypotheses. In the early weeks of this initial experience, however, she neither understood nor trusted this approach as well as she did at the end of the year. "I maintained the tradition because it was secure. I didn't know any other way to do it so I wasn't feeling as confident about what the *Supposer* could provide.... I wasn't as secure with that open-endedness as I feel now."

The teachers found their first sessions with students using the computer laboratory were not easy. Indeed, according to Barbara, teaching with the *Supposer* in the lab format, "Opened up a can of worms I wasn't prepared for." Looking back over the year, she could see the skills her *Supposer* students had developed and recognized more clearly what they lacked when they started. "It was more of a challenge than I expected because we were teaching so many new things at once: computers, geometry, exploratory learning, and abstract thinking. The kids also had to become more organized and responsible for working independently. It was just more than I was prepared for."

The teachers found that integrating an inductive approach to geometry required both them and their students to develop significantly new roles in the classroom. Pamela explained that students were accustomed to the teacher's being the "center of attention" at the front of the class. In that position the teacher was the major source of knowledge, along with the textbook, with primary responsibility for imparting that knowledge to the students. The ETC project called for teachers to pose problems and then guide and help students as they worked more independently on the problems either alone or in pairs at the computer.

Several kinds of events might occur during students' investigations that made the Willis teachers uncomfortable. Initially, students had trouble getting started and constantly called for the teacher's attention. As they worked, students might pursue lines of inquiry that led them away from the teacher's agenda and they might make discoveries or raise questions that the teacher had

not anticipated. Even if they discovered much of what the teacher hoped they would learn, she might worry that they had not learned it properly or thoroughly because she had directly taught it.

In all, this inquiry approach disrupted familiar relationships that teachers had with their curriculum and their students, replacing predictable, teacher-controlled events with activities shaped more by students' growing knowledge of geometry and mathematical reasoning. In response, the Willis teachers struggled to gain control over the new approach, and to understand how to be responsible teachers under these new circumstances.

They devoted a great deal of time to preparation of several sorts: becoming familiar with the computer and the software, trying out problems to understand how they could best be used for teaching and then developing appropriate worksheets for students, and working through problems to anticipate how students might respond. Pamela Olson referred to this process as getting the materials "under control".

> It took a lot more time to think about how I was going to approach the problems. And I had to think ahead about what the kids might be asking. When you go by the book, there's no question; they just do the problems in the book. With these *Supposer* problems they come up with all kinds of things. So you have to think what sorts of questions they'll come up with so you'll be ready to answer them....If you don't go over the questions beforehand, you can't answer their questons in class. And you don't want to be embarrassed.

Her views about preparation reflected her sense of what a teacher should be and do. Both Willis teachers anknowledged that in their school both teachers and students expected teachers to have all the answers, but that the guided inquiry approach required a different vision of the teacher. Beverly warned, "You can't go into this if you feel insecure about admitting that you don't know something or that you don't understand a problem because you're learning, too." Pamela told her students at the beginning of the course, "This was something new for me. That's what [the Geometry Advisor] told us to tell them, that we were learning along with them." Although both teachers espoused an image of themselves as learners with their students, both seemed to feel a responsibility to understand problems well enough that they rarely encountered an unanticipated response from their students.

Two anecdotes illustrate the subtlety, difficulty, and importance of the shift that this approach required in both teachers' and students' roles. Both stories reveal how accustomed roles in schools inhibited sharing responsibility for teaching and learning that the ETC innovation encouraged.

One day the teachers were away from school at an ETC meeting and a substitute teacher taught their geometry class. One of the classes took advantage of the inexperienced teacher by filing out when a bell rang part way through their session. The students knew the bell signaled lunch time for

classes on a different schedule, but they also knew the substitute would not be attuned to these vagaries of the bell schedule. The teacher's response, upon returning next day, was to punish the students by refusing to dismiss the class until all students were quietly seated at their desks. She continued this reminder of their misbehavior for several weeks. This punishment was consistent with the usual expectation that teachers must discipline students in order to make them attend to the teacher's agenda. It did not, however, encourage students to take more responsibility for their own discipline and learning. Pressing students to take more initiative may require teachers to behave in ways that are difficult and may even feel irresponsible within the traditional classroom culture.

A second anecdote points to the shift in the teacher's relationship to the curriculum. One of the ETC staff observed a geometry class in Willis toward the end of the year. The teachers had hastily developed a problem for students to investigate on the computer, knowing that the staff member would like to observe this kind of activity during her visit. In the course of their investigations, students found that a consistent pattern emerged in the ratio between the angles of a triangle in their diagram, except when the triangle was a right triangle. When the students discovered this exception, the teacher seemed puzzled and suggested that students skip over right triangles, but record data for all other types of triangles. In reflecting on this episode, the observer guessed that the teacher had designed this problem hurriedly and had not had time to explore it very thoroughly. She was impressed that the teachers had constructed such a fascinating problem that drew students to investigate an important, puzzling set of geometric relationships. She regretted, however, the lost opportunity to engage with students in a central aspect of mathematical inquiry--puzzling over unexpected findings and counter examples to discern a rule that accounts for them.

To seize upon such unanticipated but rich opportunities, a teacher must first recognize that exceptions to the rule signal an important piece of geometry, and must have a strategy for guiding students to deal with it productively. At a more fundamental level, the teacher must see herself as one who learns along with her students celebrating unexpected results as an occasion for inquiry, not as an embarrassment to be avoided. Yet this view is not comfortable for students and teachers accustomed to regarding the teacher as the one who has all the answers.

Grading students' work was also demanding. In the traditional class, each student works alone and there is a fairly narrow range of acceptable work for most assignments. On the ETC project, students worked together on more open-ended lessons. Teachers had to develop ways of tracking what individual students were producing. This was not as big a problem after the teachers became accustomed to observing individual students during lab sessions. Pamela permitted students to collect data together, but required that they produce conjectures on their own. She then used their

conjectures as a basis for grades. More open-ended problems generated a wider range of acceptable answers and teachers found that grading this work required more thought and judgment than grading the traditional assignments.

In coping with these difficulties, both teachers found that their advisor from ETC provided particularly valuable assistance. During their first experiences in the computer lab, having him in the room helped them control their anxiety. For one thing, he was a second helper who could go around and respond to students' questions. He also helped put their experiences in perspective when they reviewed lessons with him. His classroom experience teaching with the *Supposer* lent his reassurance and suggestions a powerful legitimacy in the teachers' eyes. They found him to be very well organized, anticipating their concerns and responding promptly when they asked for help. He not only suggested problems and exercises, but also reported on how his students had dealt with them and provided suggestions for modifying or extending them. They valued him as a "cheerleader" who was supportive and reassured the Willis teachers that their difficulties were not unique.

They also valued the opportunity to meet regularly with the teachers from other lab sites along with the ETC researchers. The hour and a half drive to Boston was difficult, but they enjoyed the chance to exchange ideas with other teachers, something they rarely did otherwise. "If we didn't have the support of the Group, I'd have quit," recalled Barbara. "Everybody was in the same place. When we had trouble with grading or tests, other people had the same problem. So I realized it wasn't just me, or the problem I assigned, or my students--it was a problem with this type of teaching. And that takes rising to the challenge, not dismissing it."

The ETC Geometry Group helped teachers define and deal with the problems they encountered. It also allowed them to help as well as be helped. Beverly noted, "It helped to teach the same problems that other people used, so that you could see pitfalls if they did one first or warn them if you went first. It was OK to be the leader as long as you weren't the leader all the time."

Having a colleague involved in the same project was also very helpful. The two teachers synchronized their assignments and shared materials. As they passed in the hallway between classes, they exchanged reports about how lessons had gone. They puzzled through things together as they practiced with the software at home during the summer and outside of school hours.

Both teachers recognized the importance of their principal's enthusiastic support of the project. He helped arrange space for the computer laboratory, a decision loaded with political freight in a crowded building. He helped them solve problems as they arose. For instance, when

students wanted to use the computers outside of class time, the principal agreed to rearrange teachers' administrative duties to enable them to open the lab when it was not needed for classes. He also permitted teachers to substitute supervision of the computer lab for monitoring the cafeteria or the Study Hall. To make this modification he first had to win assurance from the Teachers' Union that they would not find this change in extracurricular responsibilities a violation of their contract. His willingness to bend and modify entrenched procedures and assignments expressed his commitment to the project in a way that not only alleviated logistical constraints, but also boosted the teachers' morale.

Impacts

The Willis geometry teachers thought the project had a major, mostly positive, impact on them and their students and their classroom interactions, on the content of their geometry course, and on the school more broadly. Both teachers admitted that the project had been an enormous amount of work, but that they had enjoyed it. Pamela Olson saw that it had removed her deep-seated fear of computers and renewed her love of geometry. "Every once in a while I'm [at home doing chores] and I sit down at the computer and start doing problems. My husband says I give more attention to it than to my housework." Beverly Lewis noted the change in her teaching style. "I wasn't as secure with that open-endedness as I feel now," she said at the end of the school year.

Both teachers felt students learned more geometry with this approach. They thought the manipulability of the *Supposer* environment made geometry more accessible and memorable than it is with the traditional text-based approach. Pamela said, in an interview near the end of the school year:

> I think this *Supposer* has done a lot. I have probably taught everything out of the book that I want to teach, and I think they have retained more than if I had just used the book....They'll retain more [geometry] because they've seen it and worked with it over time.

Assigning problems with the *Supposer* reintroduced material throughout the course, whereas "with the text once you've finished quadrilaterals you don't go back to them," said Patty.

They also thought the more inductive approach helped students learn. Beverly found the students learned to pursue exploratory thinking systematically. "They had to focus on the problem itself, not take it to tangents here and there...For instance, if they found that when they reflected something and it looked pretty neat, they couldn't just go on with that. They had to focus more."

Partially offsetting these advantages were some negative effects on students' learning. The teachers thought students did not work hard enough on memorizing formulas and definitions. This

is a perennial problem, but they thought it might have been exacerbated this year for students who thought good grades on the open-ended *Supposer* assignments would compensate for poor grades on tests that required the recitation of memorized information.

Both teachers felt they had made a significant change in their role as teachers, giving up some of the authority and control that they had customarily preserved. "I think that students have a lot more to say now than before," Pamela stated at the end of the year. "Before I was always the one teaching; they didn't ask that many questions. They just accepted what I said and did what I told them to do. Now we interact more and I have time to talk to each one while they are on the computer." She felt this introduced a valuable element of intellectual excitement into the class that led some students to spend extra time in the lab outside of class searching for discoveries in geometry.

Capitalizing on this enthusiasm, Pamela introduced other mathematics software that students could use outside of class time. She encouraged other teachers in her department to incorporate some computer-based work into their courses and expected that every math class would make some use of the computers in the coming year. She believed the lab site project stimulated this shift not only by bringing hardware to the school, but also by demonstrating how software can support an approach to mathematics that is not possible with traditional materials.

Both teachers hoped to teach geometry with the *Supposer* the following year, although they planned to modify their use of the technology Pamela planned to provide more time for students to explore the software before asking them to complete a specific assignment, much as she herself had done in preparing to teach with it. She hoped this would reduce the flurry of questions in the early computer laboratory sessions. She also thought she would be better able to provide step-by-step instruction as students tackled problems rather than "just letting students go".

Beverly Lewis , seemed to anticipate a different shift, toward more exploration of problems. Looking back over the year, she thought she had "stuck with the traditional structure" at times when she could have given students more opportunity to develop their own ideas. She found herself supplying right answers for fear that students would learn misinformation. Looking back over the course she saw the value of students' learning to develop and evaluate their own ideas.

Overall, the geometry innovation appeared to have opened the way for a dramatic change in the teachers and the structure of their courses, and to have had a significant effect on both them and their students. Their school administrators were very supportive of this change at a logistical level, but the prevailing culture in the school did not support the fundamental conceptions of teachers' and

students' roles implied by the geometry innovation. The values of the school and community emphasized obedience and conformity with the status quo more than independence and active participation in inquiry. During the year, teachers struggled to reconcile new images of their course and their responsibilities with their old expectations and ongoing requirements. By the end of the year, they had changed considerably, although they both thought further change would be necessary to fully implement the new approach.

Programming Innovation

At Willis High School, Peg Jackson was the only computer science teacher. A member of the math department, she taught three programming classes each day as well as two mathematics classes. She thought being the only programming teacher had both advantages and disdadvantages. On the plus side, Peg had control over all curriculum decisions in the computer classes and she liked that independence. Because programming was a relatively new course, it did not have a traditional curriculum or standard text book like algebra, geometry, and other mathematics courses. On the down side, though, she had noone to consult with about teaching programming. " I like my freedom, but I don't like working in the dark."

Peg actively sought out opportunities for professional development. She was taking graduate courses in computer science at a nearby college and had served on the ETC Programming Research Group. Participating in the laboratory site project held some appeal as an opportunity to discuss the teaching of programming with other teachers, but she also felt pressured to participate by Willis administrators and other teachers who thought the project would bring valuable resources to the school.

Peg had taught introductory BASIC programming four times prior to the year of this project. Because it was the only computer science course, Peg included discussion of "computer literacy" topics, although she focused on teaching programming. Programm[illegible] an elective course at Willis, and tended to attract students with above average grades. Peg referred to her programming sections as "gravy classes" because they included only about a dozen students who posed few discipline problems. At Willis all students in computer science must have completed or be enrolled in their second year of a college preparatory math class. Their level of math preparation varied as did their degree of motivation, according to Peg. Some who planned to go on to college were very motivated, but she thought others lacked the incentive to do better than average; "a very few are truly personally interested".

Planning and Early Impressions

When Peg first heard about the laboratory site project from her principal, "It was presented as something that the school system was interested in doing....as though the three components [of the lab site project] would have to take place in order for Willis to participate. I had an interest in it because I'd been down to Harvard for ETC meetings before...and, of course, I could see the benefits to the school system in terms of the equipment." She also knew that the geometry teachers were eager to participate and thought they would not be able to unless she, as the school's only programming teacher, also agreed to participate. She assumed that all three innovations would have to be implemented at Willis in order for Harvard to feel that Willis was a "site which merited their attention".

With these thoughts in mind Peg attended the introductory meeting in spring 1986, intended to clarify the aims and activities of the Metacourse project to help teachers decide whether they wished to participate. She found this exposure wasn't enough to determine whether or not she wanted to use the metacourse, but it did set some ideas in her mind."My original ideas were that this was not a course that should stand by itself but rather was directed toward some of the problems which people had brought up as being places where students were weak in any programming course. .. I got the sense that they [the ETC Programming Research Group] wanted [the lessons] to be integrated into your regular material. And that they wanted the content for the metacourse to be reinforced in the rest of the course."

But exactly what content was to be reinforced was not clear. Looking back over the year she perceived that the project developers had not fully articulated the goals and underlying rationale of the metacourse. "I think that maybe because these people had been working on those basic assumptions for so long they didn't really re-express them," adequately to lab site teachers.

Despite this ambiguity, she decided to participate. By the end of the year she reported she was glad to have been in the project, but at the beginning she apparently agreed mostly because she thought that the overall the project would benefit the High School. "I just think it was presented and everyone said this is something really great that we can get into, and so we all said, " OK, we can do it then."

Implementation Process

Teaching the metacourse took some adjusting for Peg, as it did for all the lab site teachers. A primary concern at first was how to fit the metacourse into her regular course. "Probably the

biggest problem that I had was related to the ... extra time that it took to develop the lessons, figure out where they go, and just fitting them in." This difficulty was exacerbated because only the first three lessons of the metacourse were distributed in early September. The remaining six lessons were sent out one at a time as the Programming Group completed revising them. Teachers usually received a lesson very shortly before they were expected to teach it.

Knowing how much to prepare the students for metacourse lessons was tricky. Peg reported that her students found the first lesson too easy perhaps because she had already taught much of the material it covered. Compensating for this problem, she did not prepare them enough for a subsequent lesson.

She also found the approach and activities a bit foreign. "The style was something that wasn't quite my own." In particular, the overhead projector was unfamiliar, although she concluded that it became a useful addition to her accustomed teaching materials. Also, she was uncomfortable with lecturing for an entire 45 minute period as the metacourse lessons called for her to do. "I do that from time to time but ... usually I stop and let them work on the computers and try some different things out." Her preferred mode was made possible by her classroom arrangement where students could sit at desks facing the chalkboard on the front wall or could move easily to the dozen microcomputers arranged on desks lining the other three walls of the classroom. She realized that teachers who did not conduct all their lessons in the computer lab must concentrate computer-based activities during lab sessions and reserve lectures for days when they did not teach in the lab. Peg thought the metacourse format might be better suited to circumstances where lecture and lab-based lessons were strictly separated.

Despite these minor wrinkles, Peg moved quickly through the lessons, becoming more comfortable with the material and the format as the metacourse went along. "I don't think that I had too much difficulty in varying it; although it wasn't tuned to the way I would teach without it, it wasn't so much different that it bothered me at all.... And I think all of us need to get out of the ruts that we are in every once in a while."

In coping with the process of incorporating the metacourse lessons into her own teaching, Peg found talking with the other laboratory site teachers especially helpful. "[Another teacher] was teaching the lessons either at the same time or slightly before me, and I'd talk to her. She would come in and say, 'Oh, be careful of this' and it was really very helpful." Peg also used particular problems and strategies that other teachers mentioned either at meetings or on the electronic network that linked lab sites participants.

Peg thought the electronic network could have been more valuable than it actually turned out to be. The network was easy for her to use, both because she was already familiar with computers and because the modem was connected to a computer and telephone line right in her classroom. It was much less convenient for the geometry teachers, Peg noted, because they were novice computer users at the beginning of the project and had to travel down the hall to her room to use the network. Peg found that other teachers did not use the network as often as she did and assumed these reasons provided a partial explanation. She also noted that the network was not operational until partway through the fall semester at the end of which the major implementation phase of the metacourse was completed. In addition, she thought the Programming Group never defined and followed through with a project that would make network participation valuable or necessary. The Programming Group decided to share problems on the network and Peg responded by posting a problem, but other teachers did not respond. Accordingly, her own participation on the network tapered off. "As long as you have the mail and the telephone, why use a third channel that might not get through anyway?" In contrast, she said that the geometry teachers would regularly find mail on the network from their advisor that they wanted to read.

Peg found that beyond the challenge of weaving metacourse lessons into her own course lay a more subtle task of melding her style with the spirit of the metacourse. Part of this difficulty arose because the metacourse lessons were very thoroughly spelled out, including lesson outlines, specific examples, and even suggested scripts for many portions of lessons. She felt uncomfortably constrained by this degree of specificity. Before teaching the metacourse another time, she thought she would revise many of the examples. "I think the kind of examples a teacher gives are one of the things that stands out in a teacher's style....It certainly was nice to have those examples because you can see the way other people think. But at the same time, the students knew they weren't mine."

Despite this level of specificy, Peg thought the ETC Programming Group did not fully convey their goals and the rationale behind the metacourse to the lab site teachers. She recognized from the earliest meetings that the metacourse was intended to address some typical weaknesses in an introductory programming course, but not to contain the full course. She thought some of the other teachers misunderstood this point and did not realize that these lessons would merely enrich, not substitute for, their regular course. She also noted that a metacourse of this sort, designed to complement or bolster an existing course, makes assumptions about what the course already includes. Given the variability in introductory programming courses across schools, she thought the developers would have done well to spell out those assumptions.

In retrospect, Peg realized that to achieve a seamless blend of her own expertise with the most

effective parts of the metacourse would require thoughtful weaving of bits and pieces of lessons. To do justice to both required a thorough understanding of the rationale behind the metacourse, something she felt she progressively acquired over the course of the project.

Impacts

Peg thought the impact of the metacourse on her, her students, and her course was subtle, but positive. The metacourse lessons did not dramatically change her teaching approach. When presenting a metacourse lesson, she tended to lecture for a longer period than she would ordinarily do and she used devices (e.g. the overhead projector) and examples that did not feel quite comfortable. But these changes were not a radical shift from her usual behavior.

She did think she had benefitted a great deal from participating in the project. The opportunity to talk with other programming teachers helped put her own approach in perspective and enriched it. She found the Programming Advisor very helpful. He not only provided materials and assistance in implementing the metacourse but helped her gather other materials that she didn't have easy access to.

The main effect on the content of her course was to make certain implicit concepts and strategies more explicit. She usually taught most of the topics addressed by the metacourse, but often did not specifically identify them. Peg cited the lesson on program patterns as a good example:

> In other years I hadn't spent whole lessons talking about those things as patterns. What I would do is just develop different programs and, in the course of developing those programs, the patterns would be used so much that the kids would become used to seeing them without them being specifically identified. Not to say that was good. I think that the metacourse identifying patterns really made it alot easier for the kids who don't have that intuitive grasp of what's going on. But it did slow them down, too.

In making these concepts explicit, the metacourse prompted Peg to rethink her goals in teaching programming and reassess her lessons to be sure she emphasized her priorities. Looking back over the year, Peg reflected that her goals had not been clear when she first started teaching programming. "It was new and kids wanted to learn programming. Just being on a computer was enough....Kids were thrilled just being able to make thinks come up on the screen and do things the way they wanted....Now that the newness is wearing off you really have sit down and tell them, 'This is why we're doing this.' So probably the metacourse came at the right time for me....I think that just discussing the goals of the metacourse helped clarify the goals that I had."

Peg suggested that the metacourse might have had a bigger effect on her than on her students directly. She found that it helped her sharpen the focus of her course and her lessons and diagnose her students' confusions more accurately. She also thought several of the lessons were particularly well designed so that students learned concepts or strategies effectively. But she doubted that most students would have done significantly better with the metacourse than with her traditional course. The most able students "were going to get it no matter what you do." The least able students "who in the past have had problems figuring out what to do first, just getting started, still have the problem," she thought. In summary, the metacourse helped with building some particular skills, but Peg doubted that it significantly altered her students' overall programming performance.

DISCUSSION

The ETC laboratory sites project reveals the process of integrating computer technology and guided inquiry into the regular secondary curriculum, a goal espoused by many but reached by few. Its chronicle includes tales of difficulties, of solutions or at least strategies for coping, and of successes ranging from glimpsed possibilities to significant educational accomplishments. Taken together, the stories suggest why advocates lobby for using computers in the schools, why their dreams are slow to materialize, and how this slow process may be accomplished. In this section, we will review these stories to clarify factors that affected the implementation of ETC-developed innovations which seem likely to influence any efforts to introduce new technologies into the secondary school curriculum.

The basic question investigated in this project was, "What does it take to carry out guided inquiry with computers in regular school settings?" The answers fall into two categories of conditions. One deals with the prerequisite conditions that must be met before teaching with computers is possible. These include access to hardware and software and related equipment. The other category concerns the conditions necessary to integrate new technology into one's curriculum and accustomed teaching style. The latter requires a more subtle, less visible set of materials, knowledge, beliefs, skills, and institutional supports.

PREREQUISITES FOR INTRODUCING NEW TECHNOLOGIES

People who want to use new technologies to improve the core curriculum of schools, tend to underestimate the difficulties involved in acquiring, installing, and scheduling access to computer hardware. They may regard these matters as minor logistical hurdles to be dealt with briskly in order to get on with the important business of teaching and learning. Yet these hurdles are often

quite high; to ignore them is to risk becoming mired in a bog of delayed shipments, missing cables, electricians' strikes, lack of furniture, or internecine wars over time and territory. A brief review of these potential quagmires gives appropriate warning.

Buying Hardware

The decision to buy computers is usually a complex one in a school system. The purchase is large enough to merit careful thought, yet in most schools the process is not standardized, as it is for such regular purchases as text books and supplies. Sometimes schools buy their own equipment, often with special budgets from fund-raising drives or grants. Other times the central office makes the decision about what to purchase and where to place the machines. Whatever the process, there is likely to be many a slip twixt the vision of teaching with the computers (if such a vision existed at all) and the final decisions about purchasing the hardware. Through these slips, various agendas will emerge. By the time the hardware arrives, it is likely to be viewed as an essential prop in a great variety of dramas whose authors are unaware of each other's plans.

Preparing Facilities

Locating a place to put the computers can be difficult. In many schools, space is at a premium and people become fiercely territorial. Most school teachers endure work conditions that would make an office worker shudder. Few have an office, a telephone that they can regularly use in private, or easy access to copy machines. Some do not have a desk of their own where they can store papers or work in peace. Classrooms are often heavily scheduled so that teachers move around during the day rather than settling into one place where they are free to create the kind of atmosphere conducive to their work. Under these circumstances, the demand for space to set up computers can trigger a panic of protectionism. Each corner of the school is someone's bailiwick and is layered with a history of bargains. Negotiating a place for the computers may involve the equivalent of a title search, and a long process of diplomacy and horse trading.

Finding space is only part of the battle. Then it must be prepared to accommodate the computers. In one lab site, the only territory not firmly reserved in advance was a room condemned because of poor air quality. The liaison, who was a veteran at the school and a native of the community, knew the right people and the intricate process necessary to construct a duct to bring fresh air into this forgotten cell. The provision of electrical outlets, appropriate furnishings, and storage space can also be major challenges. Their acquisition often depends on a sequence of acts by myriad members of a bureaucracy who probably care more about other items on their complex agendas.

Installing Hardware

Once the computers and the prepared space are brought together, someone must unpack and install. At one lab site school, computers sat in their crates for weeks until people with the necessary skill found time in their schedules. During installation, it is likely that some machines will be found to malfunction, some necessary cables will be missing, and the need for additional power strips and extension cords will be discovered.

This rehearsal of logistical problems associated with hardware and related equipment suggests the kinds of difficulties to anticipate. It also points out the need for an experienced staff person to guide the process, so that the inevitable negotiations lay the foundation for a productive use of the new technology.

Acquiring Software

Identifying and acquiring useful software is a major challenge to most classroom teachers. The potential size of this difficulty was eclipsed in the laboratory site project because it developed around selected pieces of software. In many schools, however, the hardware arrives before teachers have a clear idea of how they might use it. Teachers then face the daunting task of how to locate, review, evaluate, and choose software that could enhance their educational program. There are now thousands of software packages, a multitude of catalogues, even a large number of organizations which publish software reviews. In this welter of possible resources, most teachers find it difficult to know what to look for and where to find it.

Once a piece of software is selected, it must be purchased and, if it is to be used with a whole class in the computer lab, multiple copies must be obtained. Here again, the process may require the approval of several layers of bureaucracy and the acquisition of related materials such as extra discs and computer paper.

Scheduling Access

When the new technology first becomes available, there may be few teachers ready to use it. Thus, for a while, scheduling access to the computer lab may be fairly simple. As an increasing number of teachers wish to use these facilities, however, orchestrating access requires juggling conficting demands. In one lab site the liaison, who took responsibility for scheduling access to the computer laboratory, found herself caught in continual crossfire between teachers who wanted to reserve time in the lab.

The overriding message from this review of logistical challenges is that the introduction of complex new technology requires the sustained effort of a knowledgeable coordinator. The lab site liaisons played this role successfully and illustrate the kind of skill it requires. Lab site liaisons were veterans in their school systems, broadly knowledgeable about their norms, values, and mores. They knew how to penetrate layers of bureaucracy when a task, such as acquiring a new telephone line, required approval from several different places. And they found the back door when the official paths seemed blocked. They needed technical skill to set up and maintain equipment and to assist teachers who were new to computers. In many cases the liaisons were diplomats who mediated conflicts among colleagues who wanted incompatible arrangments in the computer laboratory. All of these activities take time. The lab site liaison who was also a full-time teacher found that sqeezing her liaison work into a full schedule was extremely taxing.

INTEGRATING NEW TECHNOLOGIES INTO THE SCHOOL PROGRAM

As complex as these prerequisite conditions may be to achieve, they merely set the stage for actually incorporating the technology into the content and process of a teacher's course. The integration of a new technology into the existing curriculum and activities of a classroom involves an accommodation of the new and old approaches to subject matter, pedagogy, and underlying beliefs about the basic purposes and process of education.

Prior research on the implementation of educational innovations has often traced the innovation from its inception by developers into the implementation settings where it is inevitably altered. Indeed, at the far end of the implementation chain, the person who actually puts an innovation into practice is seen to exert a great deal of influence over the form it takes (Weatherly & Lipsky, 1977; Farrar, DeSanctis, & Cohen, 1982). From this perspective, observers of the implementation process tend to notice factors such as organizational constraints and individual controls (sometimes called resistance) that they often construe as barriers to progress.

More recently, researchers have paid more attention to teachers' beliefs and views of classroom practice (Doyle and Ponder, 1977; Lampert , 1985; Cohen, 1987; McLaughlin, 1987). Looking from inside the classroom, these researchers have tried to understand the assumptions and conditions that occasion and sustain traditional classroom practices. From this perspective educational innovations may look like potential disruptions of conditions carefully designed and precariously balanced to achieve multiple complex purposes under difficult circumstances.

Focusing on the evolution of an innovation as it travels through the implementation process offers one view; understanding the personal and organizational context where an innovation is expected to be implemented provides quite a different view. If these two perspectives are combined, the introduction of educational innovations can be studied in terms of the "goodness of fit" between the innovation and elements in the implementation context. The laboratory site case studies offer an opportunity to conduct this sort of analysis with attention to four such elements: curriculum, customary practices, technology and underlying beliefs about teaching, learning, and knowledge.

Curriculum Fit

Congruence

In describing teachers' "practicality ethic" Doyle and Ponder (1977) distinguish two aspects of teachers' concerns about the fit between their curriculum and an innovation. Congruence is one aspect--the extent to which the new innovation ...sses key elements in their accustomed curriculum. Instrumentality is another--the extent to ...ch the new approach is spelled out in procedural terms which take classroom contingencies into account.

While teachers vary in the degree to which they feel compelled to "cover the curriculum" (a point we will discuss further in considering the influences that shape teachers' beliefs and prac...s), most teachers regard teaching the material in their syllabus as a priority responsibility. Innovations which directly address core elements in the existing syllabus are more likely to attract the interest and cooperation of teachers.

The three lab site innovations varied in the degree to which they were recognized as congruent with the standard curriculum. The programming metacourse was specifically designed to "fit" with existing curriculum. It dealt with topics covered in all beginning programming classes, using materials designed to be generic, not keyed to any particular text. Designed as single lessons to be inserted throughout a semester course, the metacourse lessons were clearly organized in a recommended sequence and designed to absorb only a small amount of precious class time. The value of this feature became apparent in listening to teachers talk about the number of days, even minutes, allotted to particular topics by their required course scope and sequence.

The science unit dealt with particular subject matter which appears in several different secondary level science courses. Heat and temperature are topics addressed in the standard freshman physical science course, in chemistry, and in physics. The materials prepared by the ETC

research group were designed primarily for research purposes, to teach a particular set of ideas. They were not designed particularly to "fit" with the standard curriculum of any secondary science course. This mismatch was immediately apparent to the advisor hired to assist with the implementation of the science innovation in lab sites. He responded by gathering and sequencing additional teaching materials and individual lesson plans. He then attempted to help each lab site science teacher select from among these materials a set that addressed their particular curriculum. In this process, many teachers stuggled to "steal" time from their usual scope and sequence because the new lessons required more class time than they usually allotted for teaching topics to be covered.

The geometry innovation presents a third case, different in several respects from both of the other two. Rather than specific lessons, the geometry innovation consisted of a new approach to teaching geometry. This approach integrated inductive reasoning into the standard geometry course, focusing on developing theorems by making conjectures and testing them empirically. The traditional geometry course teaches students to deduce a broad set of theorems from a limited number of axioms. Many geometry teachers regard this elegant, deductive, logical structure as the major intellectual agenda in their course, even more exciting and important than the geometry itself. The innovative approach dealt with much of the same geometry content as the traditional course, but added a whole new dimension to the usual material on geometric reasoning. The innovation also disrupted the sequence of the standard syllabus, revealing new relationships among topics and making the usual order of topics seem inappropriate. In effect, the innovation addressed much of the usual geometry course content, but in a way that not only added new content to the traditional curriculum, but also scrambled the old syllabus in profound ways.

Geometry teachers tended to regard this additional agenda as an assault on their accustomed deductive approach. It took time away from their regular lessons and disrupted the coherence and sequence of their traditional course. They struggled to discern the connections between the inductive and deductive strands of the course and to help their students recognize these relationships.

Instrumentality

The accounts of these three innovations also reveal differences in their completeness from a teacher's perspective. The programming metacourse included an abundance of classroom ready materials. These included teaching materials, such as lesson plans, presentational diagrams duplicated as overhead projector slides, and even a script to help teachers understand exactly what they were expected to cover in a lesson. They also included materials for students, such as work

sheets, problem sets, and "minimanuals" which summarized important definitions in an easy-to-reference format. All of these materials were organized by lesson in the chronological order in which they were to be used. Certainly the metacourse was the most "instrumental", in Doyle and Ponder's sense. Indeed, lab site teachers seem to have found these materials almost too complete, giving them the uncomfortable feeling that they could not sufficiently adapt the lessons to their own style and their students' needs.

The science materials, even after the advisor had supplemented those offered by the ETC research group and organized them into suggested sequences, were not nearly as complete. The materials included worksheets for laboratory-based lessons, prepared (by the advisor) in the accustomed form: objective, materials, procedures. Teachers were left on their own, however, to outline a sequence of lesson plans into which these lab sessions might fit. As teachers attempted the innovation they discovered that the courseware they were given needed to be modified for their students and supplemented with additional materials.

The geometry innovation was also comparatively incomplete. In this case, however, the developers had carried out prior implementation studies and understood more thoroughly the gaps and shortcomings in the materials they provided. They warned teachers that they would have to select from among the problem sets and then translate these problems into exercises and materials suitable for their own students. Similarly, the developers understood that teachers would have to choose a sequence of exercises and problems that corresponded effectively to the structure of their course. The advisor helped teachers design such materials to extend and translate the innovation materials into terms that fit their classroom needs. Nevertheless, by comparison with the programming metacourse, the geometry innovation required teachers to devote much more time and effort to designing, producing, and pilot testing materials.

Fit with Existing Practice

Another dimension of integrating a new technology into the core school program concerns its compatability with the accustomed pedagogical process and classroom organization. For lab site innovations this process involved some form of guided inquiry that attempted to connect the results of students' inquiry with the teacher's agenda for a course. The teacher's role in this pedagogical approach includes several aspects, not necessarily in the order listed below:

1. **present information**, including directions for activities and explanatory models,
2. **pose problems** structured so as to provoke inquiry that challenges students' ideas and builds their reasoning skills,

3. **guide students' inquiry**, providing enough guidance that students examine key concepts and practice key skills while encouraging students to learn how to guide themselves,

4. **integrate students' ideas with the teacher's agenda,** helping students construct their understanding and build confidence in their own powers of thought, while making sure they learn the subject matter the teacher regards as important.

Each of these roles requires a teacher to possess a certain set of pedagogical skills. At the very least this approach requires teachers to manage two general kinds of classroom arrangements. One involves the teacher leading the whole class; the other requires the teacher to break the class into smaller groups of students, organized and supervised so that they can accomplish productive learning without the teacher's constant presence. Clearly, students also need to know how to play their parts in each of these kinds of learning activities. Students who have been taught to listen to lectures do not necessarily know how to participate in whole class discussions, nor to investigate problems independently or to cooperate with partners in a small group.

The lab site innovations varied in the extent to which their implementation called for teachers and students to take on new roles different from their accustomed practice. Again the programming metacourse appears to be the most compatible with the teachers' prior practice. Most programming teachers were accustomed to structuring their course so that some lessons consisted of presentations by the teacher to the whole class, some took place in the computer laboratory with students working independently at their own terminals, and some consisted of synthesis lessons where students' findings or products were analyzed in terms of the teachers' agenda. The metacourse lessons were designed for teacher-led sessions, but presumed that the other types of lessons were also included in the course.

The science lessons were designed for the student inquiry, where students worked independently in small groups investigating problems or conducting experiments. The developers of the science innovation assumed that teachers would lead discussions with the class where they helped students analyze and interpret the findings from their independent investigations. ETC researchers did not, however, supply materials or assistance to support this component of an effective guided inquiry approach. Lacking both a clear articulation of these expections and the support for meeting them, many lab site teachers found it difficult to help students connect results from their experiments with the concepts the innovation was intended to teach.

In theory, the science innovation was consistent with a general approach familiar to science teachers. Science courses, particularly at the secondary level are generally presumed to include laboratory-based, hands-on sessions as well as teacher-led lectures and discussions. In practice,

however, many science teachers find laboratory sessions difficult to manage. Teachers vary considerably in the extent to which they and their students are practiced in the skills required to make such sessions educationally effective. Several of the lab site science teachers found that these lessons presented a managerial challenge. Their students had not practiced their roles in conducting independent laboratory investigations. Instead students forgot to bring previously-distributed directions to class, they did not know how to divide responsibilities among members of a lab team, they were unfamiliar with standard laboratory equipment (such as thermometers) and procedures (such as recording data in ways that could be interpreted). To the extent that science teachers and students were unaccustomed to incorporating laboratory sessions into their course, the lab site project did not fit usual practice.

The geometry innovation fit even less well with the customary practice of geometry classes. Mathematics classes throughout elementary and secondary school are notorious for their lack of opportunities for students to engage in inductive experimentation. Perhaps more than any other subject, math is taught by the traditional "chalk and talk" method with the teacher at the front of the room addressing the whole class. Geometry teachers and students were profoundly challenged by the roles they were expected to take on in the lab site innovation. As one teacher of both programming and geometry said, "I'm used to breaking up my programming class for independent projects, but certainly not in geometry."

Technological and Logistical Burdens

A third dimension of comparison between the innovation and existing practice is technological. We also consider logistics in this section, because technologies have associated space, schedule, and materials requirements. The lab sites, like most schools, could not equip each classroom with sufficient computers for all students. Therefore computer-based lessons must usually be held in computer laboratories which served a variety of classes. The computer lab had to be scheduled in advance. Any additional materials and equipment had to be transported to the lab from the regular classroom and usually had to be removed at the end of the lesson so that the lab could be used by other classes. The three lab site innovations varied in the degree to which they required teachers and students to incorporate new technologies and attendant logistics into their lives.

Logistically the programming metacourse was again the least demanding of the three. Programming teachers and students were of course accustomed to using computers. Access to computers was a normal component of their course arrangements. The overhead projector was the

only technology required by the metacourse which was unfamiliar to some teachers, but the difficulties in acquiring and using this machine were very minor.

The science innovation was considerably more challenging. It involved the use of computers equipped with rather elaborate peripheral devices, as well as a significant amount of more traditional laboratory apparatus, such as beakers of water, graduated cylinders, and thermometers. Many of the science teachers had not previously used computers in their teaching, and had to overcome initial ignorance and trepidation. Like many of their students, they were unfamiliar with the concept of a user's menu and with the general model of how a computer functions. Yet the computers constituted only part of the unfamiliar technology. The peripheral microcomputer-based laboratory equipment used in this innovation was complex and fragile. Understanding the setup and functions of the apparatus was difficult. Further, the equipment was prone to malfunction in ways that novices found hard to diagnose, let alone repair.

The logistical requirements of the science innovation were also daunting. Much of the traditional materials required by the science lessons--water, beakers, heating plates, glassware, ice--are commonplace in science laboratories. In this case, however, they all had to be transported to the computer laboratory often some distance, even several floors away from the science classroom. The two settings were not only remote, but incompatible in the eyes of their users. Just as the science teachers were unaccustomed to computers, the other computer lab clients were nervous about having water spilled on the machines, and unhappy having alien equipment attached to them.

None of these problems was insurmountable, but they combined to create a significant technological and logistical hurdle for participants in the science project. Coping with them required assistance from computer laboratory assistants, ingenuity to find rolling carts and storage places, and tolerance from teachers and students who lugged pails of water and other equipment up stairs and down corridors. Mitigating these challenges was the science teachers' and students' general familiarity with "wet labs". They were accustomed to using complex apparatus that must be handled with care.

Geometry teachers faced somewhat less challenging technologicial hurdles, yet because few of them had taught with any complex technology, the hurdles seemed quite high. Unlike the science teachers they had no elaborate peripheral devices nor extensive equipment to deal with. Nevertheless, the computers and the rather complex menu of the *Geometric Supposer* presented a daunting challenge to teachers who had little or no prior experience with computers. In order to make the *Supposer* an integral part of their course, teachers needed to become fluent with the

software, an accomplishment that required hours of "messing around" and working through class exercises. Without this familiarity teachers might march through a planned lesson, but would not be able to tap the power of the technology if they deviated from their predetermined course.

For the geometry teachers, logistical hassles also presented a noticeable nuisance. In planning the lab site project, the geometry project developers had recommended that teachers working with them have access to a computer lab for every class. Based on prior attempts to carry out this approach with beginning teachers, they had concluded that the ideal classroom offered enough computers for every pair of students, a large monitor to be used for whole-class discussions, and sufficient desk space for students to spread out their papers away from the computers. Few lab sites could provide this ideal arrangement. Instead, most teachers had to reserve the computer lab in advance, and move their class there when they wanted to conduct a computer-based lesson. This requirement was particularly inconvenient for new teachers who had no basis for estimating how long a particular sequence of lessons might take. They found it difficult to predict more than a day in advance whether their class should meet in the computer laboratory or in their regular classroom.

Fit with Epistomology--Views of Teaching, Learning, and Knowledge

Underlying a teacher's decisions about the content and sequence of the curriculum and about his or her usual way of organizing and conducting lessons is a set of assumptions about what knowledge is, what teachers do, and how students learn (Berlak & Berlak, 1981). Aside from changing curriculum, practice, and logistical arrangements, an innovation may challenge a teacher's basic educational philosophy (Cohen, 1987). To comprehend the salient discrepancies between an educational innovation and existing conditions in the classroom, it is important to examine the usually tacit epistomologic assumptions held by teachers on the one hand and by the proponents of an educational innovation on the other.

To overlook this dimension of comparison may invite teachers' superficial compliance with the surface level routines of a new practice without eliciting their endorsement or even understanding of the goals and approach it was intended to exemplify. Worse yet, the developers of educational innovations may confront what appears to them to be opaque and immovable "teacher resistance". To the reformer, this may seem to reflect simple conservatism or misguided fear of the unfamiliar. From the teachers' perspective, this phenomenon is more likely to feel like integrity and commitment to serve multiple goals and clients (e.g. students, parents, and administrators) in the context of largely unalterable constraints. Close examination of both reformers' and teachers' underlying educational philosophies may explain otherwise puzzling difficulties in the educational change process and suggest ways of dealing with them.

The Educational Technology Center involved school-based educators on all its projects and aspired to heed their views at every phase of the research process. This was a conscious attempt to anticipate and deal with the realities of schools and classrooms which in the past have often foiled the application of educational research to practice. This effort does appear to have shaped the work of ETC researchers in ways that enhanced the practical applicability of their findings. Nevertheless, ETC was based at a university and most of its projects were led by academics. Placed in historical context, the laboratory site project can be viewed as a recent addition to a long line of efforts by academic reformers to alter practice in the schools. Like many of their predecessors (Cohen, 1987), this set of innovations reflected an epistomology quite different from the prevailing views in most schools.

ETC research projects tend to espouse a teaching approach consistent with a long-standing progressive educational approach and reflecting what is recentlly referred to as a constructivist pedagogy. The assumption behind this approach is that students learn through a process of changing their minds, and that teachers must support this process by helping students construct connections between their own ideas and the new information they encounter. This approach and its underlying assumptions are strikingly different from traditional school practice. As many researchers have documented, most school lessons consist of "frontal teaching": teachers present information and students listen then rehearse this delivered knowledge through seatwork and homework exercises they complete by themselves (Goodlad, 1984; Cuban, 1984; Cohen, 1988). The ETC innovations introduced in lab sites challenged this traditional "knowledge transmission" paradigm with a "knowledge construction' paradigm.

Activities Entailed by the Innovation

The lab site innovations varied, however, in the degree to which they directly challenged the operating assumptions of the participating teachers. Part of the variation stemmed from the extent to which an innovation's particular activities reflected a constructivist pedagogy. The programming innovation, for instance, consisted mostly of teacher-directed presentations while the science strand included only laboratory exercises where students worked through pre-specified experiments. Neither of these directly required the teacher to help students construct understanding by making connections between their own ideas and the teacher's agenda. Both the programming and the science innovations could be dutifully carried out by teachers who did not espouse a constructivist pedagogical philosophy. Granted such teachers would violate the spirit of the ETC innovations, but the particular activities and materials in these two innovations could be used by teachers who basically operated within the knowledge transmission paradigm.

This was not true of the geometry innovation. The most striking feature of this innovation as presented to lab site teachers was its emphasis on an inductive approach to the subject matter. The entire approach depended on engaging students in a process of exploring geometry empirically, making and then testing conjectures on the basis of actual data. In the words of the geometry advisor, the task for teachers was to "create an intellectual community in the classroom where students and teachers shared responsibility for teaching and learning." Teachers working with this innovation had to confront directly the challenge of constructing knowledge with their students. This innovation brought teachers face to face with basic questions about knowledge and authority. Who has authority to create knowledge? On what basis is the content of a course or the progression of a class discussion decided? How does a teacher decide to divide attention between exposing students to already made knowledge and helping them learn how to make knowledge themselves?

Fit with School Values and Structures

The extent to which the lab site innovations challenged teachers' accustomed epistomology can be viewed as a function of "fit" between the innovation, the teacher's pedagogical philosophy, and the values and structures built into the teacher's school context. We have already discussed variations in the innovations themselves, but the cases also reveal differences in the implementation process among teachers and across sites.

Some variations in teachers' reactions reflect their personal beliefs and practiced approaches. There is some evidence from the lab site cases that such personal preferences are shaped by teachers' assessments of their students' needs. Teachers frequently claim, for example, that less able students require more directed instruction than brighter students who are more likely to make interesting conjectures, engage in abstract thinking, and intuit the teacher's agenda without explicit instruction. Teachers who endorse such claims might alter their pedagogical approach depending on the characteristics of students in a particular class.

The lab site cases suggest teachers' beliefs are also shaped by features of the school context within which they work. Teachers felt especially pressured to "cover the standard curriculum" if their students were evaluated on the basis of standardized examinations designed to assess mastery of that curriculum. In cases where there was not such an exam (e.g. programming) or where the teacher was assured that an examination would be designed which reflected the innovative curriculum, teachers felt freer to incorporate new and more open-ended approaches.

Besides being influenced by specific school policies regarding curriculum, teachers' pedagogical philosophies appear to be shaped by the process whereby policies are set within their

systems. Just as students' learning is influenced by the "hidden curriculum" discernible in the ways teachers interact with them, just so teachers' beliefs are shaped by the way they are treated. In schools such as Norville, where teachers regard themselves as highly skilled professionals, where they are expected to exercise judgment over curricular and assessment policies, and where the expectation that they be continuing learners is built into the course assignment process, the structure of the school encourages teachers to think of themselves as makers and critiquers of knowledge. The ready provision of administrative support creates the flexibility necessary for teaching experiments. These circumstances encourage teachers to view themselves as knowledge makers. As such they are more likely to see their students in the same light.

In contrast, when rigid curriculum and assessment guidelines are set in ways that leave teachers feeling disenfranchised, teacher efficacy is undermined. If administrators tend to push their own policies more than they encourage teachers to initiate change, they may encourage a top down flow of authority. This flow is likely to shape the social structure of classrooms where it must be counteracted if students are to be encouraged to think for themselves. When the prevailing values of a school community emphasize discipline over critical thinking, the transmission paradigm is reinforced and the construction paradigm is jeopardized.

In summary, the implementation of guided inquiry approaches are shaped in part by the prevailing values and structures of the school context. Structures include physical architecture, policies, communication patterns, formal and informal personnel organizations, and ways of making decisions especially about key matters such as curriculum, testing, staff development activities, course and student assignments, schedules, and resource allocation. Such structures both reflect and shape underlying values. These may either reinforce or undermine the values and educational philosophies behind guided inquiry.

Recommendations

The laboratory site research implies recommendations for further research, for future efforts to connect educational research with practice, and for efforts to support the integration of new technologies into the curriculum and practice of core school programs.

Further research is needed to understand in more detail the process of integrating technology-enhanced guided inquiry into regular school settings. Specific questions to be addressed include: What exactly are students expected to learn from such approaches? What do teachers need to know, do, and have in order to carry out such approaches? How can materials, teachers education activities, and school organizations be designed to support these approaches?

The laboratory site research sketches the scope of the answers that might be anticipated, and suggests that the answers will vary depending on subject matter, grade level, teacher and student characteristics, and school system values.

The implications of this project for future collaborative research and school change efforts are positive. Extensive collaboration at ETC between school practitioners and educational researchers led to the production of research results which were directly applicable in classrooms. The collaborative effort to support this application not only reaped practical benefits in the schools, but also improved the research itself, deepening the analyses that were possible and indicating fruitful lines of investigation. Prior relationships built during the early research and development phases of work by ETC projects paved the way for the implementation research carried out in this project.

Yet the laboratory site project also yields cautions about school/university collaborative efforts. Many of the products of research, despite their collaborative development, needed extensive elaboration and supplements before they could be readily incorporated into practice. The significant differences between university-based and school-based participants--in assumptions, priorities, and expectations--created gaps that were difficult to bridge. Effective, mutual education by school and university participants is a delicate, demanding, protracted process.

Finally, the lab site project suggests several practical recommendations:

1. Do not underestimate the complexities of satisfying even the prerequisite conditions for introducing computer technology into the schools. Arranging for hardware, software, facilities and related equipment, and schedules requires the sustained coordination of many kinds of resources and expertise.

2. This research confirms prior investigations of educational change in underscoring the importance of : innovative materials and activities which spell out both the underlying assumptions and the instrumental particulars while encouraging teachers to adapt, extend, and elaborate themthem; initial teacher education combined with support over time as teachers work a new approach into their classroom; assistance from colleagues as well as from people experienced in carrying out the innovative approach (Bird, 1986; Huberman & Miles, 1986; Lieberman & Miller, 1986; Little, 1986; Loucks & Zacchei, 1983; Showers, Joyce & Bennett, 1987). The lab site project also makes clear that when an innovation challenges teachers' basic educational philosophies, direct attention must be paid to helping teachers reflect on this challenge and cope with the intense feelings it can engender.

3. Efforts to support guided inquiry in schools must address not only the education of individual teachers, but the school contexts in which they work. Curriculum requirements, standard assessment instruments, rigid schedules, and school policies that emphasize accountability to externally-determined standards rather than a culture of collaborative inquiry (Goodlad, 1987) are likely to work against constructive approaches in the classroom. Teachers cannot be expected to sustain radical changes in their curricula and practice that are not reinforced by the values and structures of the surrounding school system.

NOTES

[1]The Microcomputer-Based Laboratory innovation was developed by the Educational Technology Center's Heat and Temperature Research Group. Information about the group's research, including the design and effects of the innovation studied in laboratory sites, can be found in their research reports. These include: Wiser, 1987; Wiser, Kipman, & Halkiadakis, 1988; and Wiser & Kipman, 1988. Microcomputer-Based Laboratory equipment is now commercially available from HRM Software.

[2]The Programming Metacourse was developed by the Educational Technology Center's Programming Research Group. Information about the group's research, including the design and effects of the innovation studied in laboratory sites, can be found in their research reports. These include: Perkins & Martin, 1985; Perkins, Martin & Farady, 1986; Perkins et al., 1986; Schwartz, et al., 1988. The prototype Metacourse teaching materials can be ordered from the Educational Technology Center, Harvard Graduate School of Education, Cambridge, MA.

[3]The *Geometric Supposers*, (Schwartz, J., Yerushalmy, M., & Education Development Center, 1985-1987) a series of software discs, are published by Sunburst Communications, Pleasantville, New York, with supplementary materials including a textbook, problem sets, and video tapes for teacher education. The innovative approach to teaching with the *Supposers* was developed at Education Development Center and by the Educational Technology Center's Geometry Research Group. Reports of their research include: Chazan, 1988;. Yerushalmy, Chazan, & Gordon, 1988a; and Yerushalmy, Chazan, & Gordon, 1988b.

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